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CONTRACTOR REPORT

FURTHER DEVELOPMENT OF A DUAL-PROBE DIGITAL SAMPLING (DPDS) TECHNIQUE FOR MEASURING FLOW FIELDS IN ROTATING MACHINES

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Following a review of the technique, detailed descriptions are given of the procedures developed for calibrating and applying a system of two simple semi-conductor (Kulite) pressure probes to measure the velocity field from a high speed rotor. Calibration tests of a "second generation" probe set in a steady free jet, procedures for deriving calibration equations and subsequent verification tests are described in turn. Data reduction procedures and software involved in the application of the probe system with controlled digital data sampling, to obtain the blade-to-blade velocity field in a machine are documented with examples of results. Successes and potential problems are evaluated.

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1. INTRODUCTION

The development of the measurement technique reported here was required for the determination of the periodic flow field behind the rotor of a small, single-stage axial compressor. With the rotational speed of the rotor of 30,000 RPM at design conditions, the 18 blades of the rotor result in a blade-passage frequency of 9 Khz. Thus a high response measurement technique was essential. As reported earlier in Ref. 1, the means for determining the time-averaged flow at all speeds is available, and such measurements have been made to 50% speed.

The basic idea of the present technique was established some time ago (Refs. 2, 3, 4). This report gives a brief review of the measurement concept, results obtained with a first set of probes, and describes in detail the calibration and application of a new set of probes. The new probes have the advantage of being only two-thirds the size of the old ones.

2. MEASUREMENT CONCEPT

As described in detail in Ref. 2, a dual-probe digital sampling technique is used to determine the flow field behind the rotor in a real time regime. The technique incorporates two high response Kulite pressure transducers (Fig. 1). Using two trigger signals from the compressor shaft (one per revolution and one per blade), digitization of signal data can be controlled from the probes which are shown in Fig. 2. 128 locations can be selectively triggered for any one blade passage, thus giving good resolution for the specific area to be covered. The control device for the computer acquisition of the data is the PACER. Details of this device, which was developed in-house, can be found in Refs. 2 and 3.

Two major changes to the hard- and software of the PACER were made recently which are reported in Ref. 4. These changes made the lock-on to blade passing frequency totally automatic and reliable, and significantly reduced the total time for acquisition of a set of data. During the period reported here, several errors were found in the work presented in Ref. 4; Appendix A identifies the errors and their corrections.

The measurement system consists of two pressure probes, one the so-called type "A" probe which is essentially a total pressure probe, and the so-called type "B" probe, a total pressure probe bent up 35° from the zero pitch, zero yaw axis, in the plane of zero yaw. The PACER allows data to be acquired from each of the two probes when they are at identically the same location with respect to the rotor. The probes can be rotated about the sensor tip. It is noted that their outputs when set at different yaw angles could as well be considered as the output of different probes of fixed geometry. Earlier studies have shown the dependency of a total pressure and a type "B" probe on yaw angle. Appendix B gives a brief discussion and outlines the use which can be made of the probe characteristics.

In knowing the output for a certain yaw angle of the "A" probe and its output for zero yaw angle, as well as the output of the "B" probe for zero yaw angle at the same relative location, three different pressures are known for what might be considered to be a single equivalent multi-sensor probe. Reference 1 shows how such pressures can be reduced to values of pitch, yaw, and magnitude of the velocity vector. The zero yaw angle must be found first by comparing the left- and right-hand sides of the type "A" probe output as a function of yaw.

As shown in Appendix B, the type "A" probe output as a function of yaw angle in a steady uniform flow is symmetrical about a position where the probe is aligned with the flow (referred to as the zero yaw position). If in an unknown flow the yaw angle is not zero, by rotating the probe and finding two equal pressure readings separated by a certain angle difference and selecting the mid-point between the two corresponding angles, the unknown yaw angle can be determined. This procedure is in principle the same as the pneumatic balancing of a conventional probe (see Ref. 1). However, in an actual measurement situation the pressure output is not given as a continuous function of yaw angle. In practice, the data acquisition system allows digital recording of data for 5 to 11 different probe yaw angles. Figs. 3(a) and 3(b) give a comparison of calibration data and an approximation using a fourth-order polynomial for nine data points. It is evident that the characteristics of the probes allow a good representation of their output to be obtained for $P_A = P_A(\alpha)$ and $P_B = P_B(\alpha)$ (α = yaw angle) if only a few values are given. From these analytic functions the values $P_{A\ max}$ (maximum output of the "A" probe), $P_{B\ max}$ (maximum output of the "B" probe) and a value P_{S_A} can be determined very easily. P_{S_A} is found from $P_A = P_A(\alpha)$ where a difference in yaw of 126° separates right and left branches. This difference is chosen because for ±63° of yaw the type "A" probe output corresponds closely to static pressure.

Details of the methods used to derive the pitch angle and Mach number from the values of $P_{A\ max}$, P_{S_A} and $P_{B\ max}$ will be discussed later in detail.

In acquiring data from the compressor at a steady operating condition, for each of 128 positions in the blade-to-blade direction across a selected blade passage, pressure data are acquired from the two probes set at 5 to 11 probe yaw angles. Thus at each blade-to-blade position $P_A = P_A(\alpha)$ and $P_B = P_B(\alpha)$ can be approximated and yaw and pitch angles and Mach numbers can be derived.

3. SECOND GENERATION PROBES

In order to improve spatial resolution and keep effects such as the probe stem interference as small as possible, a new set of Kulite probes was built.

3.1 Probe Design

The so-called second-generation probes incorporate Kulite semi-transducers of the type XC062. The transducers measure 0.062 inches in diameter and are roughly two-thirds of the size of the first generation transducers. Figure 4 shows the probes in detail. The other difference compared to the first probes is the angle of the tip of the "B" probe; it is at 35° rather than 55° with respect to the zero axis. The reason is that for a range of 30° to 50° angle of attack the relationship between pressure output and angle of an inclined pressure probe is almost linear, while for higher angles it can reach a minimum and become double valued. An angle of 35° should give good resolution for pitch angles in the range of -5° to +15°.

The probe tips are covered with machined caps which have eight holes arranged in a circle. This way the area where the transducers are located is shielded while there is still sufficient area for the air to get into and out of the minute volume above the membrane. A frequency response in excess of 100 Khz is retained when the screen is used.

3.2. Temperature Sensitivity

High response semiconductor transducers are generally sensitive to temperature changes. That is, changes in the temperature of the surrounding medium will produce changes in the indicated pressure although there has been no change in the pressure level. In the transducer manufacturer's specifications it is quoted that a change of $100^{\circ}F$ might result in a misreading of as much as 2% of the full range (25 PSI) of pressure. On request the transducers can be built so that only 0.5% misreading for the same conditions should result. Thus a $100^{\circ}F$ temperature change should produce no more than 0.125 PSI or--equivalently--3.46" H_2O misreading.

The relationship between transducer voltage output and pressure is known to be linear (Refs. 2 and 3). Temperature changes result mainly in a shift of the intercept rather than the slope of the linear relationship. Since the temperature of the flow in the compressor is expected to be about $50^{\circ}F$ higher than ambient, an error of 1.7" H_2O might be expected to be present in the pressure measurement if no account was taken of the temperature sensitivity, assuming the manufacturer's specification to be accurate.

A simple test was made to check the temperature sensitivity of the "B" probe. The probe was inserted into a container which was vented to atmospheric pressure but which could be heated. With the probe connected to the data acquisition system in the usual way, the container temperature was changed and the voltage output of the probe was recorded. Figure 5 shows the effect of a temperature change of about 60°F over a period of four minutes. A corresponding increase of some 2.4" of water in the indicated pressure was observed, corresponding to about 0.6% of the full transducer range for a temperature change of 100°F. This was consistent with the sensitivity quoted by the manufacturer.

For an average flow Mach number in the compressor of 0.7, with a corresponding dynamic head of 154 inches of water, an apparent shift in the transducer intercept of 1 to 2 inches of water is not large. Also, since the shift would be similar at different probe angles (assuming the transducer temperature would not change significantly), measurements based on differences between pressures from the same probe set at different angles, would be little affected. However, as readings from the "A" and "B" probe are both involved in calculating the pitch angle, the probes must give absolute pressure levels accurately. Therefore there is need for on-line calibration as data is acquired at any new test condition.

4. PROBE CALIBRATION

4.1. Calibration Procedure

The range of Mach number, pitch and yaw angle over which the probes were calibrated, had to cover the ranges which were expected in the compressor measurements. The freejet used for the calibration, which is described in Ref. 1, is capable of Mach numbers up to 0.9, pitch angles from -45° to $+45^{\circ}$ and yaw angles from 0° to 360°. Figures 6(a), (b) and (c) show details of the probe hook-up and instrumentation which was used. Table I gives the input/output assignment list for the data acquisition system.

The "A" and "B" probes were calibrated separately. The probe outputs were each recorded for a total of 9 pitch angles (-15° to $+25^{\circ}$ in 5° increments) and 6 Mach numbers (0.2 to 0.7 in 0.1 increments). For each of these 54 configurations the probes were yawed from -80° to $+80^{\circ}$, as data were continuously recorded. This procedure served to establish the complete pressure vs. voltage output characteristics of the probes, information to be used later in the analysis and interpretation measurements in the compressor.

The transducers were scaled using bridge adjustments to give engineering units on the DVM. The angle potentiometer was set to read linearly in increments of 0.1°.

The Kulite transducers were scaled to read in increments of .01 inches of water, differential pressure. The slope and intercept of the Kulite transducer were checked and adjusted as necessary before taking data at each new test condition. The intercept was adjusted to zero by applying the jet reference stagnation pressure to the reference side of the probe transducer with the probe tip aligned with the flow and balancing the transducer bridge. The slope was set by adjusting the output of the transducer to be equal to the jet stagnation pressure with atmospheric pressure as reference.

For each configuration of probe, Mach number, and pitch angle, the procedure was as follows:

(i) Reference measurements for the jet (stagnation pressure and temperature, and ambient pressure) were recorded.

(ii) The probe was swept steadily from -80° to $+80^{\circ}$ yaw angle as 150 data values of both probe voltage output and yaw angle potentiometer reading were acquired by the computer (Fig. 6). The jet reference measurements were recorded again.

(iii) The procedure in (ii) was repeated but with the probe yaw angle swept back from $+80^{\circ}$ to -80°.

The three sets of reference measurements were compared to verify the steadiness of the test conditions. When all data were taken, a printout was produced on the line printer and a plot of pressure versus yaw angle was generated on the X-Y plotter.

For each probe, the procedure in (i)-(iii) was repeated for each pitch angle with the jet Mach number fixed. The jet Mach number was then adjusted to the next value and the complete procedure repeated again.

4.2. Data Acquisition and Storage

For each of the 54 configurations a total of 640 numbers were stored in one data file as a 2 by 320 array. The computer program used for the data acquisition was &KALIB (on cartridge 26, FORTRAN IV). The program is listed in Appendix C together with program &YAW (on cartridge 26, FORTRAN IV). Both programs (&KALIB and &YAW) are acquisiton programs for the calibration of type "A" and "B" probes. The difference is that program &YAW records--in a more conventional way--data from one fixed yaw position as the average of ten readings for up to 31 positions, while program &KALIB gathers data for continuously varying yaw position.

It was found that the average of multiple samples taken at a fixed yaw position did not give more accurate results than a single reading. Figure 7 shows a comparison between the output obtained with the two different data acquisition methods. The good agreement is an indication of the steadiness of the flow in the free jet. Figure 8 shows the output of a total pressure Kulite probe held fixed in the jet over a period of 4 minutes, during which 1000 single readings were recorded. The largest disturbances shown in Fig. 8 are probably the result of distinct changes in the ambient pressure resulting from doors being opened or closed in the building, rather than fluctuations in the jet itself.

The data acquisition program &KALIB is fairly simple and contains explanations in the program listing. Details of the data arrangement in the array are given in the program listing (Program &KALIB, statement numbers 46 through 77).

4.3. Type "A" Probe Results

Figure 9 gives an example of the type "A" probe data output at fixed Mach number for each of nine pitch angles. Shown is the probe voltage output versus yaw angle. Such plots provided a visual check of the acquired data. Table II gives an example of the data recorded for one Mach number and one pitch angle for the "A" probe. All the data in Table II are stored in one file for each configuration. Table III gives a guide to the data files for the "A" probe calibration. They are stored on cartridge 26. The file names follow the following logic:

X Y K Z R R

where

X = A for the "A" probe, or = B for the "B" probe

Y = 2, 3, 4, . . . --Mach number x 10

K = K, Kulite

Z = P for positive or = N for negative pitch angle

RR = 15, 10, 05, etc., = magnitude of the pitch angle

All data taken for the "A" probe appeared to be well behaved and useful throughout.

4.4 Type "B" Probe Results

First measurements with the "B" probe showed poor to unusable results. The output of the probe as a function of yaw angle was unsymmetrical for positive or negative yaw angles. Figure 10 shows the output at one Mach number, for the full range of pitch angles. An investigation of the probe tip under the microscope showed that some of the holes in the protective screen at the probe tip were partially blocked by particles of dirt or glue (Fig. 11(a), and (b)). The holes were cleaned and the calibration rerun. Figure 12 shows the results at a Mach number of 0.4. The characteristics of the probe were seen to be much improved and satisfactory for the intended application. Table IV gives the list of the data file names as stored on cartridge 26.

4.5. Calibration Data Analysis

For the "A" probe the output of the probe as a function of yaw angle $P_A = P_A(\alpha)$ was analysed for each of the combination of Mach number and pitch angle. First, the maximum value, P_A max, was calculated as the maximum value of a fourth-order polynomial curve fit in the

$-20^{\circ} \leq \alpha \leq 20^{\circ}$. Over this limited range the curve $P_A = P_A(\alpha)$ was fairly flat and a very precise determination of the maximum value was possible. Second, to establish values of P_{S_A} for each curve, (see Section 2), the data were surveyed to find the yaw angle closest to -63°. Data at this and at four values above and four values below this particular yaw angle were approximated with a second-order polynominal and the corresponding value of P_A, designated $P_{S_{A_L}}$ yaw was calculated. A second-order polynomial approximation for this part of the curve was adequate since the characteristic was nearly linear in this range (see also Appendix B). The same procedure was used for the right hand side of the characteristic to establish the value, $P_{S_{A_R}}$, at a yaw angle of $+63^{\circ}$. The two values were found to be the same to within a small deviation for all 54 configurations. The value of P_{S_A} was calculated as the average of $P_{S_{A_L}}$ and $P_{S_{A_R}}$. Figure 13 is an illustration of the data reduction.

The only data needed from the "B" probe was the maximum pressure output at each test condition. This value always occured for a yaw angle of zero degrees when the flow was aligned. The maximum was found by approximating the output values of P_B over the yaw angle range $-30^{\circ} \leq \alpha \leq 30^{\circ}$ with a fourth-order polynomial and solving for zero slope. The corresponding yaw angle was found to be very close to zero for all 54 configurations.

Figure 14 shows a curve $P_B = P_B(\alpha)$ for one Mach number and one pitch angle with the value established for P_B max.

The values of $P_{A\ max}$, P_{S_A}, and $P_{B\ max}$, so derived, were considered to be analogous to the outputs of a conventional pneumatic multi-sensor probe. The calibration and reduction of measurements to values of Mach number and pitch angle (the yaw angle was always zero) could be handled in exactly the same way as was done for the combination temperature-pneumatic probe (see Ref. 1). The dimensionless velocity, X, was used instead of the Mach number, M where X is defined as $X = \frac{V}{V_t}$ where $V_t = \sqrt{2\ C_p\ T_t}$, the "limiting" velocity. The quantity X can be expressed in terms of Mach number as

$$X = \frac{\frac{\gamma-1}{2} M^2}{1 + \frac{\gamma-1}{2} M^2}$$

For each of the 54 test conditions, using the values P_A max, P_{S_A}, and P_B max, the coefficients β and γ were calculated where

$$\beta = \frac{P_{A\ max} - P_{S_A}}{P_{A\ max}} \qquad (1)$$

$$\gamma = \frac{P_{A\ max} - P_{B\ max}}{P_{A\ max} - P_{S_A}} \qquad (2)$$

and a third coefficient, δ, was examined where

$$\delta = \beta \cdot \gamma$$

β is derived from values of the "A" probe only. The "A" probe is insensitive to pitch angle as long as it does not exceed $\pm 15^{\circ}$ to $\pm 20^{\circ}$. Hence γ provides the measurement of the pitch angle. The coefficients β , γ , and δ are discussed in detail in Ref. 1.

The data for a complete calibration are given in Table V. It can be seen that at fixed Mach number the value of β is always about the same regardless of the pitch angle while γ changes significantly with pitch angle. The changes in γ with changes in Mach number are seen to be small.

If X is expressed as a function of β and γ , $X = X(\beta,\gamma)$ and ϕ , the pitch angle is expressed as a function of β and γ , $\phi = \phi(\beta,\gamma)$ the functions $X(\beta,\gamma)$ and $\phi(\beta,\gamma)$ can be approximated with polynomials using the methods described in Ref. 6, such that

$$X = \sum_{i=1}^{L} \left\{ \sum_{j=1}^{M} C_{ij} \beta^{(j-1)} \right\} \cdot \gamma^{(i-1)}$$

$$\phi = \sum_{i=1}^{L} \left\{ \sum_{j=1}^{M} D_{ij} \beta^{(j-1)} \right\} \cdot \gamma^{(i-1)}$$

where C_{ij} and D_{ij} are constant coefficients. Figs. 15(a) and (b) show the surfaces which were obtained for $X(\beta,\gamma)$ and $\phi(\beta,\gamma)$, respectively.

The programs written to approximate $X = X(\beta,\gamma)$ and $\phi = \phi(\beta,\gamma)$, based on the subroutines given in Ref. 6, are &REST8 and &REST9. The programs are described in detail in Appendix D. It is noted that the coefficients were derived for the pitch angle expressed in radians.

A check of the approximation was performed in order to establish its quality. For the measurements of β and γ from the calibration X and ϕ were calculated using equations (3) and (4). The results were compared with the corresponding values known to have been set when the measurements were made. Errors in the dimensionless velocity, ε_X, and errors in the pitch angle, ε_ϕ, were defined as

$$\varepsilon_X = \frac{X_m - X_c}{X_m} \cdot 100 \qquad (5)$$

and

$$\varepsilon_\phi = \phi_m - \phi_c \qquad (6)$$

where the subscription m denotes the value measured or known to have been set and subscript c denotes the value calculated using the surface approximation.

The error ε_X is expressed as a percentage of the measured value while for the pitch angle the absolute difference in degrees between measurement and calculation is calculated. A percentage error in angle is meaningless close to **zero** pitch angle.

Table VI gives the coefficients obtained for the X and ϕ surfaces. Also shown are the errors ε_X and ε_ϕ obtained using equation (3) and equation (4). Approximations were derived for each of 36 possibilities consisting of combinations of first to sixth order approximation for β and first to sixth order approximation for γ.

The coefficients shown in Table VI gave the best results on average over the range of the calibration. They are stored as 7 by 7 arrays under the file names shown on cartridge 26. It is noted that the errors shown in Table VI are an indication only of the degree of accuracy of the approximation technique.

5. VERIFICATION TESTS

Two tests to evaluate the accuracy of the calibration and of the data reduction technique were made: (1) The raw data from the calibration were treated as test data and the reduction procedure to calculate X and ϕ was applied; (2) The probes were mounted together on the freejet, the flow was adjusted in Mach number and the two probes were set together to the same pitch angles, which were unknown to the operator (see 5.2.). Data were acquired at specific yaw angles and reduced as in the compressor application. The results are described in the following paragraphs.

5.1. Verification Using Calibration Data

From the calibration test, the pressures for the "A" and "B" probe were recorded for fixed Mach number and pitch angle as $P_A = P_A(\alpha)$ and $P_B = P_B(\alpha)$ for a range of yaw angle of $-80^\circ \leq \alpha \leq 80^\circ$. These distributions were each approximated using a sixth order polynomial, so that values P_A and P_B could be interpolated at any yaw angle. For the "A" probe 9 yaw angles were chosen ($\pm 65^\circ$, $\pm 45^0$, $\pm 30^\circ$, $\pm 15^\circ$, 0°) so that the range of yaw angle necessary to handle the data reduction was covered. Since for the "B" probe sufficient values are required to determine only the maximum output, 9 different yaw angles for a relatively small range were chosen ($\pm 30^\circ$, $\pm 22.5^\circ$, $\pm 15^\circ$, $\pm 7.5^\circ$, 0°). Arrays PA(9) and YAWA(9) were generated to contain pressure and yaw angles respectively for the "A" probe and similarly PB(9) and YAWB(9) were generated for the "B" probe. These data were then in a format as if they were produced by the data acquisition program for compressor measurements, and could be reduced in the same way.

From the fourth order polynomial for the "B" probe data, the maximum value P_{Bmax} and yaw angle at which it occured were stored, for each data set.

PA(9) vs. YAWA(9) and PB(9) vs. YAWB(9) were approximated using fourth order polynomials. For each data set the curve $P_A = P_A(\alpha)$ was searched for the yaw angles where the spread between left and right branches was 126°. Corresponding to definitions used in the reduction of calibration data, the pressure determined at the left branch was P_{SA_L} and the one at the right branch was P_{SA_R}. These pressures were as defined here, the same and were equivalently equal to the value P_{SA} (see Fig. 13). $P_{A\ max}$ was calculated using the fourth order polynomial $P_A(\alpha)$ at the value of yaw angle midway between the values corresponding to P_{SA_L} and P_{SA_R}.

β and γ were calculated using equations (1) and (2) for each data set. Using these values, the coefficients from data files MISTXV and MISTIFI and the equations (3) and (4), the corresponding values of X and ϕ were computed. The yaw angle was taken to be that corresponding to the value P_{Bmax} because the "B" probe had a clearly defined maximum whereas the "A" probe did not (see Figs. 13 and 14). The values so obtained for X, ϕ, and α using this reduction technique were compared to the corresponding values known to have been set and recorded during the test. Errors were calculated following equations (5) and (6). A third error, ε_α, for yaw was calculated using

$$\varepsilon_\alpha = \alpha_m - \alpha_c \qquad (7)$$

where α_m was the measured yaw angle and α_c was the yaw angle calculated from the "B" probe data. Since α_m was always zero during the calibration, the error ε_α so defined was equal to minus the value calculated in the reduction procedure.

The calculations described required extensive data handling. A program was written (EVALU) to read the two data files (for the "A" and "B" probes) and carry out the calculations. The program accesses and reduces data for one configuration (Mach number and pitch angle) at a time. It prints the calculated and measured values and the errors defined in equations (5), (6), and (7) before returning automatically to read the files for data from the next configuration. Program EVALU is described in detail in Appendix E.

Table VII shows a comparison of the measured and calculated data. Values for Mach number from 0.3 to 0.7 and pitch angle between 0° and 15° are given since these are the range of values expected in the intended application. The average error in X (or velocity) was about -0.4% with a maximum value of -1.336%. The average pitch angle error was 0.12° with a maximum value of 1.36°. An average yaw angle error of 0.6° was obtained with a maximum error of -1.16°. Figure 16(a), (b) and (c) show these errors plotted as functions of Mach number and pitch angle. No significant trends were detected in these data except perhaps in ε_{α}. Table VII shows that the yaw angle error was always negative at an average magnitude of roughly half a degree. This is probably an indication of the fixed error involved in mounting the probe on the freejet.

It should be noted that the probe mounting used on the freejet and on the compressor were not the same. After the calibration and verification tests were made on the freejet, the probes were mounted in special actuators for use on the compressor. First however, the assembled probe and actuators were mounted in turn on a six foot long, four inch diameter pipe which was fed by the laboratory air supply. In this pipe, due to its length to diameter ratio, a steady symmetrical airflow parallel to the pipe centerline was assured. For different Mach numbers--pitch angle was constrained to zero degrees--each probe was yawed about its tip to either side. By comparing left and right branches of the indicated probe output the yaw angle vernier was set to zero at the point of symmetry, corresponding to aligned flow. The probe was secured in the actuator so that for compressor measurements, zero yaw corresponded precisely to alignment with the axial flow direction through the machine.

5.2. Verification on the Freejet

In order to verify the probe calibration and data reduction in a known flow, the probes were mounted together on the freejet. Only the yaw angle of one probe (the "A" probe) could be read using the data acquisition system. The probes were displaced peripherally at an angle of 90° to each other (see Fig. 6). While the tip of the "B" probe was on the centerline, the tip of the "A" probe was retracted radially about one inch from the centerline to avoid flow interference between the probes. Both probes were mounted on the same type of pitch angle adjustment device.

In the test procedure the probes were set in unison to controlled pitch angles and Mach numbers which were unknown to the operator. At each setting, the two probes were each rotated to 9 different yaw angles ($\pm 65^{\circ}$, $\pm 45^{\circ}$, $\pm 30^{\circ}$, $\pm 15^{\circ}$, 0°). Data were taken for each of the 9 yaw positions. The pressure readings recorded were the average of 10 sucessive samples. Before the actual test the zero drift of the sensors was checked. For the "A" probe this was done by comparing the probe output when set to zero pitch angle with pressure. For the "B" probe, the probe was set to -35^{o} in pitch (see Fig. 4) and a similar comparison was made. The data taken were not stored but only printed. Appendix F contains the computer program TEST which acquired the data and performed the data reduction.

In order to check the yaw angle determined by the reduction procedure the probe yaw angle data were artificially offset. The 9 yaw positions recorded were changed by adding a constant to each: $65^{o}+X$, $45^{o}+X$, $30^{o}+X$, $15^{o}+X$, $0^{o}+X$, $-15^{o}+X$, $-30^{o}+X$, $-45^{o}+X$, $-65^{o}+X$. The data reduction procedure should then produce a value for the yaw angle equal to X.

Table VIII shows results of the verification tests. Shown are the results for values of Mach number and pitch angle which are typical of those to be expected in the compressor. The errors given in Table VIII are defined as

$$\varepsilon_X = \frac{X_s - X_c}{X_s} \cdot 100$$

$$\varepsilon_\phi = \phi_s - \phi_c$$

$$\varepsilon_\alpha = \alpha_s - \alpha_c$$

where index s is the set condition and c the calculated value.

The values of ε_X, ε_ϕ, and ε_α obtained were considered to represent an acceptable accuracy for the planned application of the technique. In particular, the accuracy of the pitch angle measurement was encouraging. The pitch angle was of particular concern because the distribution of pitch behind the rotor was a particular goal of the intended measurements which could lead to important conclusions concerning the flow through the rotor. As shown in Tables VII and VIII, the errors in pitch angle measurement appear to be acceptable.

6. APPLICATION IN COMPRESSOR TESTS

Complete results of compressor measurements made with the probe system will be reported later. Some initial measurements are reported here to examine and illustrate the reliability and accuracy of the probe system and of the data reduction. Since the data acquisition in the compressor is more complicated than in calibration tests on the freejet, the procedures and the programs used are described in detail.

6.1. Necessity of an Online-Calibration

The semi-conductor transducers are, to some degree, sensitive to temperature change as well as to differential pressure change. If a relationship between differential pressure and voltage output of the transducer was established by calibration before the compressor was started, there would be no guarantee that this relationship would remain valid while the machine was running. A total temperature rise of 25°F occurs in flow through the rotor and the actual temperature of the probe itself must increase, but can never be known precisely. The magnitude of the probe temperature rise is large enough however that the change in the transducer's voltage/ pressure relationship must be taken into account in some way. This is done through online calibration.

6.2. Online Calibration

Although there is a temperature sensitivity, the relationship between the voltage output of the transducer and the differential pressure is found to be always linear (Ref. 2, 3). Thus, if e denotes the voltage output and ΔP the corresponding differential pressure, the equation

$$\Delta P = i + S \cdot e \qquad (8)$$

describes the calibration, where i is the intercept and S is the slope.

The transducer is arranged in the probes such that any desired constant pressure, P_r, can be applied to the back, or reference side, of the transducer. The unknown pressure on the front of the transducer, P, which is varying in time, is given by $P = \Delta P + P_r$, or

$$P = i + S \cdot e + P_r \qquad (9)$$

The on-line calibration procedure establishes values for the slope and intercept while the compressor is operating at the speed and flow rate at which probe data are required. The procedure to establish the slope is the same for both the Type "A" and Type "B" probes. The procedure for the intercept is more elaborate and quite different for the two probes. The procedures are described separately in the following paragraphs.

6.2.1. Procedure For Slope

At a given steady machine condition, the time average probe pressure, $\overline{P}$, is constant. Because of thermal inertia it is reasonable to assume that both the slope S and the intercept i are also constant, although unknown. If two different reference pressures, P_{r_1} and P_{r_2}, are applied to the transducer in turn, and the corresponding time-averaged output voltages $\overline{e_1}$ and $\overline{e_2}$ are recorded then, from equation (9),

$$\overline{P} = i + S \cdot \overline{e_1} + P_{r_1} \tag{10a}$$

and

$$\overline{P} = i + S \cdot \overline{e_2} + P_{r_2} \tag{10b}$$

combining these equations, it follows that

$$S = \frac{P_{r_2} - P_{r_1}}{\overline{e_2} - \overline{e_1}} \tag{11}$$

Equation (11) provides the means to calculate the slope of the transducer from measurements. In practice four to five different reference pressures are applied and the slope is calculated as a linear approximation (by least squares) to the variation of $\overline{e}$ vs. P_r.

6.2.2. Procedure For Type "A" Probe Intercept

The time averaged flow conditions in the measuring plane are established using the combination pneumatic and temperature probe reported in Ref.1. The probe determines values for the Mach number, pitch angle and yaw angle*. The combination probe tip, with its arrangement of four pressure tubes, is shown in Fig. 17. When the probe is aligned to balance pressures P_2 and P_3, the pressure referred to as P_1 is a measurement of the total pressure, since the flow pitch angle can not exceed about 11^o at the rotor exit. Similarly, the type "A" probe when aligned at the time-averaged yaw angle is also in principle, a total pressure probe. By equating the measured pneumatic pressure P, to be equal to the time-average of the pressure seen by the type "A" probe, $\overline{P_A}$, the intercept of the "A"-probe can be calculated using equation (10)**.

Data for the calculation of the intercept was gathered during the acquisition of time-resolved flow

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*The question of whether a pneumatic probe can measure the correct time-averaged values of fluctuating pressures, raised in Ref. 7 and Ref. 8, was addressed in Ref. 1. It was shown that for the conditions measured to date, the results of the combination probe were accurate. Nevertheless, the possibility that an increase in rotor speed, resulting in higher fluctuation pressure amplitudes and pressure ratios, might affect the accuracy of the pneumatic measurements is accepted; and close attention will be paid to it in the future.

**The "time-average" voltage could be recorded using the integrating DVM or by acquiring a large number of discreet samples at arbitrary intervals using the HP 5610 A/D converter and computing the average. In early tests, the samples for the time-average measurements were taken using the A/D converter in the so called "free-run" mode. Roughly 1500 single data samples were collected over about 15 msec. A comparison of the average values acquired this way with those given by a digital voltmeter consistently showed agreement to within $\pm 0.5\%$. Subsequently, for convenience, the DVM was used to acquire values of the time-averaged voltage S from the Kulite probes during the online calibration.

data. At each yaw angle to which the two probes were set, readings of the probe transducer outputs were recorded using the DVM. Data from the combination probe were acquired also; however, the probe's yaw angle was not changed. The DVM voltage readings from the "A" and "B" probes were approximated as functions of the corresponding yaw angles by fourth order polynomials, $\overline{e_A} = \overline{e_A}(\alpha)$ and $\overline{e_B} = \overline{e_B}(\alpha)$. The maxima of these functions were derived mathematically and designated $\overline{e_A}max$ and $\overline{e_B}max$ respectively.

The value $\overline{e_A}max$ was found to exist at a flow yaw angle very close to the yaw angle measured with the combination probe. For the A probe, a pressure coefficient was defined as

$$\overline{C_P}_{A0} = \frac{\overline{P_{Amax}} - \overline{P_S}}{\overline{P_t} - \overline{P_S}} \qquad (12)$$

The index "0" indicates that the coefficient was derived for the yaw angle where the probe was aligned with the time-averaged flow. Ideally $\overline{C_P}_{A0}$ would be unity, since the "A" probe is expected to measure total pressure if properly aligned with the flow. However, during the calibration procedure (reported in Section 4) it was found that $\overline{C_P}_{A0}$ depended slightly on the probe pitch angle, although not on Mach number. As shown in Fig. 18, $\overline{C_P}_{A0}$ varies within the range of 0.990 to 1.020. The relationship between $\overline{Cp_{A0}}$ and pitch angle obtained in the steady-flow calibration was approximated by a fourth order polynomial. Using this approximation and the time-averaged pitch angle, stagnation pressure ($\overline{P_t}$) and static pressure ($\overline{P_S}$), $\overline{P_{Amax}}$ can be calculated using Equation (12).

Knowing the values $\overline{e_A}max$, the slope s and the reference pressure (P_r), the intercept (i) of the A-probe can be calculated using equation (10). Thus the relationship between the probe and the time-varying voltage signal from "A" probe is known, using equation (9).

6.2.3. Procedure for Type "B" Probe Intercept

The determination of the intercept of the "B" probe is indirect. Unlike the "A" probe there is no matching pneumatic measurement for the "B" probe. Such an approach would be too inaccurate. The "B" probe is intended to be very sensitive to pitch angle changes, so that a very small difference in tip geometry of the Kulite and an "equivalent" pneumatic probe would cause a potentially large error in the calculation of the intercept. Thus an alternate way to derive the "B"-probe intercept was adopted.

During the online calibration procedure, the "A" and "B" probes are set to the same yaw angle as the combination probe. In this orientation, all three probes are aligned with the time-average flow vector. This flow vector is determined totally by the combination probe, and thus the yaw angle, pitch angle, Mach number, total and static pressures are known for the time-averaged conditions.

A pressure coefficients, $\overline{C_{P_B}}$ can be calculated for the "B" probe using the definition

$$\overline{C_{P_B}} = \frac{\overline{P_B} - \overline{P_S}}{\overline{P_t} - \overline{P_S}} \qquad (13)$$

If the pressure reading of the "B" probe when aligned with the flow is referred to as $\overline{P_{Bmax}}$, the corresponding pressure coefficient, $\overline{C_{P_{B0}}}$,(at zero yaw angle of the probe with respect to the flow) is given by

$$\overline{C_{P_{B0}}} = \frac{\overline{P_{Bmax}} - \overline{P_S}}{\overline{P_t} - \overline{P_S}} \qquad (14)$$

From the calibration tests reported in Section 4, values of $\overline{C_{P_{B0}}}$ were determined for each of 54 combinations of Mach number and pitch angle. These data are given in Table IX. Figure 19 shows these calibration data for $\overline{C_{P_{B0}}}$ plotted as a function of Mach number and pitch angle. While the dependence on Mach number is seen to be small, a strong and well-behaved relationship between $\overline{C_{P_{B0}}}$ and pitch angle can be ovserved. $\overline{C_{P_{B0}}}$ was viewed as a function,

$$\overline{C_{P_{B0}}} = \overline{C_{P_{B0}}}(X,\phi) \qquad (15)$$

The function in equation (15) was similarly approximated using the calibration data as a surface depending on two independent variables (Section 4.4). Appendix G describes the computer program used and illustrates the results.

Using the expression for the surface represented by equation (15), and values of the Mach number and pitch angle, given by the combination probe, at each operating point, $\overline{C_{P_{B0}}}$ were calculated. Then, using the time-averaged total and static pressures given by the combination probe measurement, a corresponding value of $\overline{P_{Bmax}}$ can be calculated using equation (14). Using the recorded value of the

"B" probe voltage output, $\overline{e_B}\max$, corresponding P_r, and the value established earlier for the transducer slope, the intercept of the "B" probe was calculated using equation (10). Thereafter, equation (9) could be used to convert time-dependent voltage readings to absolute pressure values.

6.3. Data Acquisition in TX-Compressor Measurements

The hardware of the dual probe digital sampling technique was described in Section 2. The present section describes the procedures and software used to acquire and store raw data necessary to determine blade-to-blade velocity distributions. The sequence of events is summarized in Table X.

As described in Section 2 and Section 4.5, at each blade-to-blade location sufficient data from the "A" and "B" probes were required that functions $P_A = P_A(\alpha)$ and $P_B = P_B(\alpha)$ could be established. However, the yaw angle was not known apriori for any of the 256 positions at which data were acquired. The time average yaw angle was known from the combination probe and variations in yaw angle were selected to be about this value.

It was found that yaw angle varied typically -5° to $+15^{\circ}$ from the time averaged value. Thus data were acquired for 9 different probe yaw angles covering a range of the average yaw angle minus 5° minus 65°, and plus 15° plus 65°, in order to make sure that a sufficient range was covered to define the maximum values from $P_A = P_A(\alpha)$ and $P_B = P_B(\alpha)$ for $\alpha = \pm 63^{\circ}$.

Program &ABKUL was used for the data acquisition. It is described in detail in Appendix A. Figures 20a and 20b show an output of the raw data. Shown are the outputs of "A" probe (Fig. 20 a + b) & "B" probe (Fig. 20 c + d) for all 256 positions and for the 9 different probe yaw angle settings. The plots were generated by program &WAVE which is described in Appendix I. Besides plotting data from a data file the program also offers the possibility to acquire data from one Kulite probe and plot it on-line.

All data acquired with program &ABKUL are stored in one large data file. This includes the unsteady measurement data, all the steady state data for the online calibration and the combination probe measurements. Thus each data set is complete and independent of any other information.

Table Xa shows an example of steady state data acquired for the online calibration (see Section 6.2.); values for the slopes of the Type A before (1st) and after (2nd) the paced data acquisition. This output allows comparison of the results of the two calibrations. If the corresponding values of slope differ by more than $\pm 1.5\%$, which indicates drift during the measurement period, the data are not accepted. The "intercepts" of "A" and "B" probes are also printed. These values are only used however to monitor changes during the data acquisition. The actual intercept of the voltage-pressure characteristic must be calculated from these values as described in Section 6.2. Here again a difference of more than $\pm 1.5\%$ is taken as evidence that the transducer drifted during the measurement. The other data shown in Table X is raw data which is printed out immediately after it is acquired so that it can be checked. Combination probe data are always acquired with the Kulite probe data. Table Xb shows steady-state data taken with the data from the "A" and "B" probes. For each probe yaw angle setting the same data is acquired as for the online calibration. The values "yaw A pr." and "yaw B pr." give the probe yaw angle settings (nine positions). In the third column values DCA and DCB are printed. As described in Section 6.2., these are the dc voltage levels of the "A" and "B" probes which will be used for the determination of the intercept. For each of the nine positions, values called "averaged values paced output" for "A" and "B" probes are printed. Those are the averages of the 256 single measurements of each of the probes. A comparison of these values with the DCA and DCB values--if the decimal point is neglected--show differences of up to 5%. This is because the DC values are derived for the whole rotor, while the paced output values are from two selected blade pairs only.

The single raw data file is arranged in a 20 by 256 array. Table XI shows the location of the data within that array. Column #1 contains the data for the online calibration only while column #20 is reserved for the steady state data acquired with paced data. Columns #2 through #19 contain the raw data for the nine yaw angle settings of the "A" and "B" probe, with the Type A probe data in even numbered columns, the Type B probe data in the odd numbers. Table XI also shows the hook-up for the data acquisition for the steady state data. This is explained in more detail in Appendix H. The data acquisition for one set of data including online calibrations and steady state data requires some 17 to 20 minutes.

6.4. Data Reduction

After the raw data is checked for obvious errors using program WAVE (see section 6.3.) the data reduction is carried out using a single program "ABRED". The steps in the procedure are listed in Table J-1 and Appendix J describes the program in detail.

The program first reads the coefficient files for the calibration of the A- and B-probe as well as those for the combination probe. The operator is then asked for some input concerning the amount of output that is desired. The first calculation is to determine the flow time-average properties from the combination probe measurements. The average of the readings obtained at the nine different Kulite yaw angle settings is computed since the yaw angle of the combination probe was not changed during the acquisition sequence. The results shown in Table XII are values for dimensionless velocity (X), yaw angle, pitch angle, total pressure and static pressure.

The second calculation uses these values and the acquired raw data for the online calibration to compute the intercept values of the "A" and "B" probes. It is at the user's discretion to output the steps in this process in order to check the calculations performed (see Appendix J).

The first reduction of Kulite data performed is for the time-averaged values from Kulite probe measurements. A DC voltage reading of both probes was recorded for each of the nine yaw angle positions the probes were set to. Using the results of the previously performed online calibration, absolute pressure values are calculated. These are placed in two arrays, PAA(9) and PAB(9). Arrays YAWA(9) and YAWB(9) are filled with the corresponding yaw angle values. Using fourth order polynomials a relationship is approximated giving pressures of "A"- or "B"-probe as functions of yaw angle. From these functions the values $P_{A\ max}$, P_{S_L}, P_{S_R}, P_{S_A} and $P_{B\ max}$ are derived as shown in 4.5. The flow yaw angle was assumed to be the one corresponding to $P_{B\ max}$. However, it should be mentioned that the flow yaw angle derived from the A-probe as the center value between the yaw angles corresponding to P_{S_L} and P_{S_R} deviates only slightly ($\pm 0.5^o$ to $\pm 1.0^o$) from the one found with the B-probe.

From these four pressures, coefficients β, γ and δ are calculated. Applying the calibration coefficients to these values X-- or Mach number -- and pitch angle are calculated lated. Thus the time average flow vector is determined. If it is compared to the one derived from the combination probe measurement, the differences turn out to be, typically

0.64% in Mach number

0.55^o in pitch angle

0.63^o in yaw angle

The magnitude of these differences is acceptable. Table XII shows results of an actual data set from a compressor test run. At the very top values calculated from combination probe measurements are displayed followed by the results of the online calibrations for both "A" and "B" probe. Immediately thereafter the contents of the arrays PAA(9), PAB(9), YAWA(9) and YAWB(9) are given showing the average pressure values of both Kulite probes and their corresponding yaw angles for the overall flow measurement. The values P_{S_L}, $P_{A\ max}$ and P_{S_R} derived from those are shown as well as the corresponding yaw angles. Next $P_{B\ max}$ and the yaw angle for this pressure is given.

In the following line the actual flow quantities as derived from the "A"-"B" probes are listed. XU, XAX and

BETA2 are calculated from X, pitch and yaw angle, the circumferential speed and axial speed are printed also. These values are:

XU = Circumferential speed (dimensionless)

XAX = Axial speed (dimensionless)

BETA2 = Relative flow angle in the measuring plane.

Once the overall flow vector is determined from the Kulite probes and compared to the results from the combination probe, individual measurements are reduced for any or all of the 256 positions. Whether all, one or any set of positions is reduced is operator-controlled by input parameters.

The same way the data reduction was carried out for the time-average flow vector the raw data for all 256 single positions are treated. Arrays PA(9) and PB(9) are filled with nine individual pressures of "A" and "B" probe which were derived from the raw data applying the results from the online calibration. The yaw angle settings YAWA(9) and YAWB(9) are the same nine values as before. Those are the same throughout the whole reduction since they are the ones the probes were set to. In Table XII the arrays of P_A, P_B, YAWA and YAWB are shown. Also given are arrays PAC(9), DPA, PBC(9), DPB. As mentioned previously P_A and P_B are approximated as functions of yaw angle by fourth order polynomials. In order to check the quality of that approximation, using the polynomials, values are calculated for the nine given yaw angles (PAC(9) and PBC(9)) and the difference between the measured pressure value P_A or P_B and the calculated value PAC or PBC is displayed as DPA or DPB. As long as the values DPA and DPB are smaller than ±2 inches of water (all pressures shown are in inches of water), it can be assumed that the approximation fits the data points sufficiently well.

Above the array of measured data are some reduced values. Again P_{S_L}, $P_{A\ max}$ and P_{S_R} are printed with their corresponding yaw angles. Below the array, $P_{B\ max}$ and the flow angle for this particular position are given. In the last line position number, beta, gamma, X-- or Mach number --, pitch angle and yaw angle for this position are given.

If a data reduction shall be performed for all 256 positions it is advisable to skip the print-out of the raw data and all intermediate steps (primary input). This way there will be only the print-out of the last line of Table XII for each of the positions.

6.5 Data Presentation and Evaluation

In chapter 6.4 the reduction procedure of the raw data to discrete values of X- (or Mach number), pitch angle and yaw angle for all or any of the 256 positions of measurement was described. All these flow parameters were stored in a single file and can be retrieved at any time. In order to get an idea of the flow behavior with respect to the rotor, the flow parameters were plotted as a function of the position within the rotor frame. Figure 21(a) shows the distribution of X ; Fig. 21(b) gives the yaw angle and Fig. 21(c) the pitch angle distribution. The programs used to generate these plots, namely PLOTX, PLOTY and PLOTP, are described in Appendix L.

The general behavior of the measurements was examined. For this, the assumption was made that the relative flow angle at the rotor trailing edge, β_2 , was constant for a given radius (see Fig. 22). Figure 23 shows the velocity triangles for the flow leaving the rotor. If β_2 and X_u , the circumferential velocity, are constant, any change in the Mach number of the relative flow will reflect in a change of yaw angle and Mach number of the absolute flow. Using the nomenclature in Fig. 23, at any given flow condition i the absolute velocity is given by

$$X_{v_i} = \frac{X_{u_a}}{\tan \beta_2 \cdot \cos \alpha_i + \sin \alpha_i} \tag{16}$$

Figure 24 shows X_{v_i} as a function of yaw angle. To be examined is the yaw angle corresponding to the minimum value of X_{v_i}. From Fig. 23 it can be seen that this yaw angle is $(90^o - \beta_2)$ which is indicated also on Fig. 24. Looking at Fig. 21(b) it was found that indeed the minima of X_{vel} correspond to a yaw angle of 39.11^o.

Another characteristic point in Fig. 21(b) is the maximum value (48^o) of the yaw angle. When X_{vel} was derived from equation 16 and from Fig. 24 for that yaw angle, a value of .1572 was obtained. This value was found to be consistent with the measured Mach number for that particular location.

7. DISCUSSION AND CONCLUSIONS

As pointed out in chapter 6.2 the absolute accuracy of the Kulite measurements is governed by the accuracy of the combination probe measurements. At higher Mach numbers yet to be measured, this may become a problem (see Ref. 1). Reference 7 shows that the pneumatic measurement might be incorrect if the fluctuations in pressure increase in amplitude beyond certain limits. Since the experiments of Ref. 7 were carried out using a totally different set-up for measurements of total and static pressures, the results are not directly comparable, however, an examination of the possible influence of such errors was attempted.

The assumption was made that P1 should be treated like a total pressure probe and P23 and P4 like static pressure probes. It was assumed that an error in the measurements of P1 and also in P23 and P4, or in P1 or P23 and P4 would occur at the same time, giving a total of three possible combinations.

An error of 10% defined according to Ref. 7 was assumed. Such an error resulted in an error of 0.25% in the absolute value of the total pressure and 0.5% in the static pressure. These errors applied to the data from data file AB1901 resulted in none of the three error combinations giving a significant change in Mach number and yaw angle distribution. The pitch angle showed the only significant dependence on these assumed errors. Figure 25 shows the comparison of calculated pitch angle distribution with and without assumed errors. It can be seen that the biggest error was found for the case of a correct total pressure, but an incorrect static pressure (P23 and P4). An average difference of about one degree was found, and the distribution did not show any qualitative differences. Since the pitch angle could also be measured 0.5° too low (if P1 is measured incorrectly but P23 and P4 are measured correctly), the achievable accuracy of the pitch angle measurement is within a range of -0.5° to $+1.0^{\circ}$.

The basis of the method of application in the compressor is that the behavior of the probes as a function of yaw angle at each point in the rotor frame is the same as in a steady flow at the corresponding Mach number and pitch angle. The steady flow characteristic is known from the calibration. In order to examine the validity of this assertion, probe measurements were analysed for selected points of measurement with respect to the rotor frame. It was found that the B-probe produced the same characteristic P_B vs. yaw angle in its application as it did in its calibration. The type A probe however showed different results depending on the location of measurement. Figure 26 shows the output of the A probe reduced to values of C_{P_A} plotted in comparison with the curve of C_{P_A} as a function of yaw angle established during the calibration. It can be seen that for the time average values the agreement between test data and the calibration is very acceptable. It is also acceptable for data from near mid passage. However, the same is not true for data in Fig. 26 from the rotor wake region. Going into the wake and out of it tends to skew the top of the function C_{P_A} vs. yaw angle to different sides of the actual flow yaw angle. Near the center of the wake the probe characteristic appears to be similar to that established in the calibration. Four possible explanations for the skewing are considered:

a) Flow temperature effect on the probe output depending on the different probe yaw angle settings.

b) Probe interference due to "steady" gradient effect.

c) Probe interference due to "unsteady" gradient effect.

d) "Incorrect" averaging in a flow in which Mach number and flow angles are separately unsteady, and probe output is non-linear in M, α and ϕ.

The effect in (a) is not a probable explanation since the effect would be present also in positions outside the wake. It is also unlikely, because of thermal lag, that the sensor material could respond to the high frequencies of the wake fluctuations. The effect in (b) could give errors having the observed qualitative behavior.

In Ref. 9 it is shown that when a velocity gradient strikes a total pressure probe the apparent location of measurement tends to shift away from the center of the probe tip. The calculations carried out in Ref. 9 were applied to the geometry of the probes and flow parameters measured in the blade wakes with the A-B probes. It was found that an apparent displacement of the order of 3% of the probe outer diameter was indicated to be possible. This was considered to be negligible. However, since the results in Ref. (a) were for impact probes at zero yaw angle to the flow direction, an experiment to verify the conclusion for the A-B probes yawed in a velocity gradient, is certainly desirable.

The possibility of an unsteady error which results from the behavior of the probe itself must be considered. However, it is noted that the error is only significant where the flow is unsteady in the rotor frame. This explanation would have to be accepted if all other explanations failed, and could be verified by independent non-intrusive measurements such as LDV. However, since the error appears only in the unsteady wake the most probable cause is thought to be (d).

The existence of unsteadiness of flow parameters in the wake region is clearly evident from oscilloscope observations. The observed fluctuations are oscillations in the probe output voltage (pressure) readings, which--in the data acquisition process--are ensemble-averaged over 40 samples to represent one value of pressure for a single measurement.

From the average pressure values, pressure differences and ratios are derived and reduced to obtain a velocity vector calculated in this way is the same as the average flow velocity vector. The question clearly, is whether the flow velocity vector calculated in this way is the same as the average flow velocity vector which could be obtained if the actual velocity vector was known for the individual samples. Clearly, the probe output depends quite differently on variations in pitch, yaw and Mach number, and the fluctuations involve changes in all three.

A first attempt was made to examine the problem of averaging. Using calibration data, an array of three Mach numbers, three pitch angles and three yaw angles was selected. This resulted in a total of 27 possible flow vectors, for which the functions $P_A = P_A(\alpha)$ and $P_B = P_B(\alpha)$ were known. Since the flow yaw angle during a calibration is always zero, an "artificial" yaw angle was superimposed on the calibration data. For yaw angles different from zero, corresponding pressure values for the A and B probes were shifted by the amount of the superimposed yaw angle, but in the opposite direction.

In a first step the 27 flow vectors were averaged by averaging their velocity components U, V, W and calculating the corresponding single values for pitch angle, yaw angle and Mach number. Secondly, for each of the 27 vectors, data sets PA(9) and PB(9) (corresponding to nine different probe yaw angles) were built. These values were averaged to result in nine single values for PA, PB and corresponding yaw angles. The regular data reduction procedure was then applied and pitch angle, yaw angle and Mach number were calculated.

Differences between the two calculation methods were defined as:

$$\varepsilon_X = \frac{X_{af} - X_{ap}}{X_{af}} \cdot 100$$

$$\varepsilon_\phi = \phi_{af} - \phi_{ap}$$

$$\varepsilon_\phi = \alpha_{af} - \alpha_{ap} ,$$

subscript "af" meaning average from flow vectors and "ap" meaning average from pressure values.

The procedure was carried out for four different sets of data, each consisting of 27 different flow conditions.

Table XIV lists the range within which each of the flow parameters was varied and the differences resulting from the calculations. The differences obtained were not large, however it must be noted that the process of averaging which has been tested does not exactly simulate the one to which the A-B probes are subjected in the compressor. Further analysis is required to properly evaluate the effect of averaging on the probe data. In order to explain the skewing observed in the A-probe output in the wake regions, it would only be necessary to have fluctuations which were not symmetric with respect to the wake centerline, as is very likely to be the case in the wake of a highly loaded compressor blade.

In conclusion, the DPDS technique has been developed further to successfully measure three components of velocity in regions outside the unsteady rotor wake. The edges of the wake region and average conditions on the wake centerline are well defined. A limitation to the use of the present method within the wake region is thought to be due to the necessity for ensemble averaging. Further work is planned to resolve this question.

TURBOPROPULSION LABORATORY

HP9830/21 MX Data Acquisition

Port/Channel Assignments

Test A-B-Calibr

Run No. 1

Date Jan 1982

	S.V. #	S.V. #	SCANNER #1 ch		SCANNER #2 ch		SCANNER #2 ch	
1			0		0		40	
2			1		1		41	
3			2		2		42	
4			3		3		43	
5			4		4		44	
6			5		5		45	
7			6		6	Tt Tunnel	46	
8			7		7		47	
9			8		8		48	
10			9		9		49	
11			10		10		50	
12			11		11		51	
13			12		12		52	
14			13		13		53	
15			14		14		54	
16			15		15		55	
17			16		16		56	
18			17		17		57	
19			18		18		58	
20			19		19		59	
21			20		20	Pt Tunnel	60	
22			21		21	Kulite ref.pres	61	
23			22		22	Yaw Angle	62	
24			23		23	Kulite press.	63	
25			24		24		64	
26			25	P baro	25		65	
27			26		26		66	
28			27		27		67	
29			28		28		68	
30			29		29		69	
31			30		30		70	
32			31		31		71	
33			32		32		72	
34			33		33		73	
35			34		34		74	
36			35		35		75	
37			36		36		76	
38			37		37		77	
39			38		38		78	
40			39		39		79	
41								
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Table I. Data Acquisition System Hook Up.

TPL 4/01/81
JH

TUNNEL TEMP. DEG. F	TUNNEL PRESS. INCHES H2O	REF PRESS. INCHES H2O	BARO INCHES HG	
102.?372?0	46.1????0?0	-.?100000	30.0800??0	BEFORE READINGS
102.7652600	46.3000030	-.2700100	30.1000??0	BETWEEN READINGS
102.4874300	46.1999970	-.29??	30.1410030	AFTER READINGS
102.6958000	46.2000050	-.3333333	30.1066700	AVERAGE VALUES

YAWANG	KULITEOUT	CP	#	YAWANG	KULITEOUT	CP	#	YAWANG	KULITEOUT	CP	#	YAWANG	KULITEOUT	CP	#	YAWANG	KULITEOUT	CP
-81.32	-39.9600	-.872	61	-19.67	44.79000	.962	121	47.460	22.13000	.472	181	41.?60	30.??000	.6??	241	-51.01	17.67000	.36
-81.72	-40.1700	-.876	62	-18.57	45.51000	.977	122	48.680	21.58000	.458	182	41.7?0	32.3?000	.674	242	-51.23	15.45000	.3?
-81.74	-40.3600	-.878	63	-17.31	45.89000	.986	123	49.710	19.84000	.432	183	39.??0	33.99000	.72?	243	-5?.?1	14.??000	.3?
-80.75	-38.1700	-.833	64	-16.06	46.59000	1.001	124	50.540	19.41000	.391	184	36.??0	35.4?000	.751	244	-53.15	13.07000	.27
-79.72	-37.0200	-.8??	65	-14.49	47.10000	1.01?	125	51.540	15.74000	.347	185	34.??0	37.??000	.8?4	245	-54.42	1?.??000	.2?
-78.79	-34.9200	-.763	66	-12.97	47.37000	1.018	126	52.7??	15.1?000	.3??	186	33.77?	3?.??000	.832	246	-5?.07	9.93000	.16
-77.90	-32.5100	-.711	67	-12.61	47.42999	1.0??	127	53.700	13.50000	.2??	187	31.?20	39.??000	.877	247	-57.28	6.??000	.1?
-76.67	-30.4900	-.667	68	-11.63	47.35999	1.0??	128	54.570	12.66000	.267	188	30.440	40.52000	.879	248	-58.47	5.47000	.11
-75.73	-28.1400	-.616	69	-10.49	47.35999	1.029	129	55.230	11.56000	.243	189	29.?20	41.??000	.9??	249	-59.43	3.87000	.07
-74.35	-25.8200	-.565	70	-9.270	47.83000	1.02?	130	55.?10	10.30000	.216	190	27.?60	42.??000	.9??	250	-60.73	2.?3000	.04
-73.56	-24.5000	-.537	71	-8.210	47.63000	1.0??	131	57.040	7.95000	.187	191	2?.???	43.09000	.936	251	-61.?6	.?7000	.0?
-72.17	-21.5300	-.475	72	-6.740	47.57000	1.0??	132	57.770	7.77000	.161	192	??.???	43.7?000	.9??	252	-62.96	-2.3?000	-.05
-71.??	-19.0900	-.420	73	-5.560	47.41999	1.0??	133	58.620	6.??000	.137	193	??.???	44.38000	.9?4	253	-63.77	-4.??000	-.0?
-70.71	-17.9200	-.393	74	-3.660	47.31000	1.0??	134	59.??0	-?.??000	-6.92	194	2?.7??	44.??000	.9?4	254	-64.??	-7.??000	-.1?
-69.91	-15.9500	-.352	75	-2.600	47.29000	1.017	135	60.300	4.40000	.078	195	??.7?0	44.6????	.9??	255	-66.17	-9.57000	-.21
-68.73	-13.9900	-.310	76	-1.400	47.30000	1.017	136	61.140	3.25000	.063	196	18.990	45.25999	.973	256	-67.29	-12.7100	-.2?
-68.07	-12.1700	-.270	77	-.???	46.90000	1.008	137	62.00?	1.72000	.033	197	17.660	45.45???	.977	257	-67.75	-1?.5?00	-.3?
-67.26	-9.49000	-.212	78	.930	47.02000	1.0??	138	63.1?0	.29000	-.00?	198	16.300	45.5????	.97?	258	-6?.18	-15.7?00	-.34
-66.36	-6.74000	-.153	79	2.??0	46.90000	1.008	139	63.790	-.87000	-.026	199	17.120	45.97???	.98?	259	-69.6?	-17.6700	-.35
-64.93	-3.76000	-.0??	80	2.600	47.02000	1.0??	140	64.570	-1.75000	-.045	200	13.150	4?.??000	1.00?	260	-70.??	-1?.??00	-.47
-63.77	-1.??000	-.033	81	3.?80	46.91000	1.0??	141	65.470	-4.????	-.1??	201	11.8?0	46.5????	1.0??	261	-71.74	-2?.?400	-.5?
-62.54	.57000	.009	82	4.970	46.77000	1.005	142	66.640	-7.25000	-.164	202	11.130	46.????	1.0?1	262	-72.09	-25.3900	-.57
-61.45	2.65000	.05?	83	6.160	46.?6000	1.0??	143	67.360	-8.1?000	-.184	203	8.270	46.7????	1.0??	263	-73.53	-??.??00	-.64
-60.90	4.52000	.091	84	7.000	46.36000	1.0??	144	68.000	-10.7?00	-.2??	204	6.?40	4?.????	1.0??	264	-75.??	-3?.?400	-.67
-59.??	6.5?000	.135	85	7.?40	46.73000	1.0?4	145	68.740	-11.7?00	-.2??	205	6.???	46.????	1.0??	265	-77.55	-34.9000	-.76
-57.95	8.6?000	.15?	86	9.470	46.21000	.993	146	69.350	-13.02?0	-.2??	206	2.680	47.00001	1.0??	266	-7?.?3	-3?.??00	-.8?
-56.87	1?.25000	.215	87	11.110	46.?0000	.9??	147	70.150	-17.????	-.325	207	.960	47.????	1.011	267	-79.19	-37.3???	-.8?
-55.34	11.35000	.239	88	12.130	46.05000	.9??	148	71.?80	-16.????	-.367	208	-.190	47.????	1.0?6	268	-8?.?4	-40.1900	-.87
-54.17	13.61000	.282	89	13.??0	45.?1000	.984	149	71.630	-17.6???	-.387	209	-.???	47.57000	1.0??	269	-8?.??	-3?.6500	-.8?
-52.45	15.35000	.325	90	14.260	45.43000	.976	150	72.270	-15.????	-.4?1	210	-2.?4?	47.6????	1.0??	270	-81.38	-41.7000	-.8?
-51.45	16.67000	.354	91	15.461	45.?2000	.971	151	??.65?	-21.????	-.755	211	-3.?00	47.????	1.0??	271	-81.37	-40.????	-.8?
-50.45	17.76000	.382	92	16.3??	45.15000	.965	152	??.???	-24.8???	-.760	212	-4.?60	47.95000	1.0??	272	-81.38	-40.2400	-.87
-49.43	19.1?000	.417	93	17.??0	44.75999	.962	153	??.???	-35.????	-.734	213	-7.?60	47.9????	1.0??	273	-8?.?4	-41.1400	-.8?
-48.97	20.49000	.437	94	18.540	44.91000	.955	154	7?.???	-32.?9??	-.702	214	-?.?70	47.????	1.0??	274	-81.??	-3?.9900	-.8?
-47.38	22.04000	.470	95	19.??0	44.42000	.954	155	76.210	-29.5300	-.646	215	-1?.??	47.8????	1.0??	275	-81.3?	-41.3600	-.8?
-46.34	23.30000	.5??	96	21.?10	43.?0000	.9?7	156	77.770	-25.6?00	-.5?6	216	-1?.67	47.93000	1.0??	276	-81.??	-3?.??00	-.8?
-45.33	24.97000	.533	97	22.530	43.?1000	.941	157	77.210	-27.????	-.605	217	-1?.?4	47.71000	1.0??	277	-81.??	-4?.????	-.8?
-44.05	26.26000	.561	98	23.510	43.25?01	.9??	158	76.650	-2?.?5?0	-.577	218	-13.30	47.17000	1.014	278	-81.39	-39.6300	-.84
-42.92	27.41000	.585	99	24.510	42.97000	.923	159	73.370	-22.6???	-.497	219	-1?.?0	46.75??	1.00?	279	-81.35	-3?.5700	-.8?
-41.77	28.87000	.615	100	25.830	42.50999	.913	160	73.910	-19.67?0	-.433	220	-1?.2?	46.57??	1.001	280	-81.3?	-3?.7400	-.8?
-??.??	30.??000	.657	101	26.??0	42.22000	.907	161	72.?10	-17.1???	-.375	221	-1?.?5	45.6????	.9??	281	-81.39	-40.3?00	-.8?
-39.7?	31.46000	.674	102	27.720	41.91000	.900	162	70.650	-15.6???	-.3?2	222	-1?.??	45.07000	.953	282	-81.37	-37.5200	-.8?
-38.??	32.79000	.703	103	28.7??	40.34000	.877	163	68.420	-8.87???	-.199	223	-20.53	44.67999	.96?	283	-81.36	-3?.?300	-.8?
-37.27	33.6?000	.727	104	30.170	4?.1?000	.8??	164	67.0??	-5.3????	-.132	224	-2?.1?	44.37000	.953	284	-81.36	-3?.?100	-.8?
-36.15	35.27000	.756	105	30.960	39.48000	.848	165	65.410	-1.57000	-.041	225	-27.53	43.06000	.925	285	-81.39	-39.6600	-.8?
-34.76	36.30000	.779	106	32.150	38.56000	.828	166	63.750	2.45000	.045	226	-25.61	41.52000	.6??	286	-81.36	-3?.9700	-.67
-33.70	37.44000	.803	107	33.??0	37.87000	.813	167	61.400	3.94000	.073	227	-2?.??	41.03000	.82?	287	-81.3?	-3?.7300	-.8?
-32.71	38.13000	.819	108	33.950	37.08000	.796	168	60.690	4.97000	.100	228	-31.6?	4?.35000	.8??	288	-81.39	-39.5900	-.8?
-31.4?	3?.?600	.8??	109	34.??0	36.23000	.777	169	59.460	7.?????	.147	229	-3?.??	3?.????	.87?	289	-81.36	-41.0600	-.8?
-30.40	39.50000	.849	110	35.260	35.73000	.766	170	57.770	9.?????	.201	230	-32.?2	37.70000	.809	290	-81.38	-39.??00	-.8?
-29.6?	40.45000	.869	111	36.??0	34.41000	.7??	171	5?.350	1?.????	.245	231	-33.91	35.8????	.77?	291	-81.39	-3?.????	-.8?
-28.67	41.00999	.881	112	37.660	33.75000	.724	172	55.170	13.6?000	.2??	232	-35.42	34.76000	.7??	292	-81.4?	-39.4300	-.8?
-26.??	41.35000	.888	113	38.750	32.19000	.69?	173	53.510	15.????	.3??	233	-36.97	3?.????	.6??	293	-81.39	-39.?500	-.8?
-27.74	42.20000	.905	114	39.940	31.34000	.671	174	51.510	19.??000	.405	234	-39.1?	3?.??000	.6??	294	-81.39	-4?.??00	-.8?
-2?.15	42.60000	.913	115	40.4??	30.31000	.649	175	-0.040	2?.????	.4?3	235	-40.??	2?.??000	.6??	295	-81.36	-39.?600	-.8?
-23.83	43.07000	.925	116	41.350	29.45000	.630	176	48.670	21.96000	.457	236	-41.65	27.65000	.591	296	-81.37	-39.6???	-.8?
-24.??	43.61000	.937	117	42.7??	27.77000	.59?	177	47.540	24.2????	.512	237	-43.??	25.7????	.54?	297	-81.36	-37.6600	-.8?
-23.09	44.41000	.95?	118	44.110	26.14000	.559	178	45.760	25.37000	.553	238	-44.75	23.83000	.5?9	298	-81.36	-41.1500	-.8?
-22.12	44.79000	.962	119	45.180	24.71000	.5??	179	44.270	27.91000	.590	239	-45.55	21.77?00	.4?4	299	-81.??	-3?.7?00	-.8?
-2?.?0	44.77000	.962	120	45.410	23.32000	.4??	180	42.660	29.37000	.629	240	-47.33	19.44000	.414	300	-81.36	-37.7100	-.8?

Table II. Raw Calibration Data From A-Probe, One Mach Number, One Pitch Angle.

0.7	A7KP25	A7KP20	A7KP15	A7KP10	A7KP05	A7KP00	A7KN05	A7KN10	A7KN15
0.6	A6KP25	A6KP20	A6KP15	A6KP10	A6KP05	A6KP00	A6KN05	A6KN10	A6KN15
0.5	A5KP25	A5KP20	A5KP15	A5KP10	A5KP05	A5KP00	A5KN05	A5KN10	A5KN15
0.4	A4KP25	A4KP20	A4KP15	A4KP10	A4KP05	A4KP00	A4KN05	A4KN10	A4KN15
0.3	A3KP25	A3KP20	A3KP15	A3KP10	A3KP05	A3KP00	A3KN05	A3KN10	A3KN15
0.2	A2KP25	A2KP20	A2KP15	A2KP10	A2KP05	A2KP00	A2KN05	A2KN10	A2KN15
↑ Mach →	25	20	15	10	5	0	-5	-10	-15

Table III. Raw Data File Name Arrangements (A-Probe).

Mach ↑ / Pitch →	25	20	15	10	5	0	-5	-10	-15
0.7	B7KP25	B7KP20	B7KP15	B7KP10	B7KP05	B7KP00	B7KN05	B7KN10	B7KN15
0.6	B6KP25	B6KP20	B6KP15	B6KP10	B6KP05	B6KP00	B6KN05	B6KN10	B6KN15
0.5	B5KP25	B5KP20	B5KP15	B5KP10	B5KP05	B5KP00	B5KN05	B5KN10	B5KN15
0.4	B4KP25	B4KP20	B4KP15	B4KP10	B4KP05	B4KP00	B4KN05	B4KN10	B4KN15
0.3	B3KP25	B3KP20	B3KP15	B3KP10	B3KP05	B3KP00	B3KN05	B3KN10	B3KN15
0.2	B2KP25	B2KP20	B2KP15	B2KP10	B2KP05	B2KP00	B2KN05	B2KN10	B2KN15

TABLE IV. Raw Data File Name Arrangements (B-Probe).

DATA IS STORED IN FILE : ABNEW2 AS D(10,54)

	(1,I)	(2,I)	(3,I)	(4,I)	(5,I)	(6,I)	(7,I)	(8,I)	(9,I)
(J,1)	409.36	422.79	.0958	25	1.0540	.0030	64.41	.0322	1.0759
	409.37	422.99	.0962	20	1.0821	.1270	65.15	.0299	[illegible]
	409.51	423.13	.0961	15	1.0823	.2290	65.78	.0316	[illegible]
	409.54	423.04	.0960	10	1.0749	.4250	65.63	.0300	[illegible]
	409.54	423.38	.0962	5	1.0803	.5680	65.64	.0299	.5465
	409.68	423.33	.0965	0	1.0722	.6930	65.36	.0313	.3895
	409.47	423.09	.0965	-5	1.0971	.7860	64.90	.0304	.2278
	409.54	423.11	.0963	-10	1.0736	.8470	64.16	.0320	.2262
	409.27	422.59	.0954	-15	1.0465	.7040	62.89	.0326	.1377
	409.11	436.25	.1348	25	.9766	.0460	62.57	.0617	.9400
	409.29	436.44	.1343	20	1.0036	.1270	63.59	.0614	.8472
	409.29	436.39	.1347	15	1.0107	.3320	63.87	.0611	.6992
	409.27	436.35	.1319	10	1.0085	.4760	63.79	.0612	.5326
	409.29	436.36	.1346	5	1.0054	.6080	63.72	.0616	.3999
	409.09	436.09	.1345	0	1.0157	.7290	63.25	.0620	.2064
	409.38	436.75	.1353	-5	1.0067	.8240	62.62	.0641	.1205
	408.95	435.84	.1343	-10	.9930	.8960	61.76	.0641	.0582
	409.20	436.39	.1349	-15	.9422	.9190	60.51	.0650	.0223
	409.52	456.95	.1754	25	.9598	.0930	62.76	.1033	.9231
	409.29	456.46	.1752	20	1.0007	.2400	63.05	.1018	.7722
	409.32	456.37	.1750	15	1.0050	.3810	63.43	.1019	.6712
	409.61	457.19	.1758	10	.9964	.5160	63.50	.1030	.4937
	409.16	456.24	.1750	5	1.0167	.6390	63.22	.1042	.3234
	409.23	456.38	.1751	0	1.0289	.7430	62.94	.1096	.2567
	409.11	455.83	.1744	-5	1.0146	.8510	61.94	.1085	.1544
	409.09	455.62	.1744	-10	.9877	.9200	61.19	.1084	.0641
	409.20	455.34	.1742	-15	.9669	.9520	60.40	.1100	.0139
	408.84	484.07	.2171	25	.9541	.1220	63.37	.1523	.8482
	408.84	483.67	.2165	20	.9790	.2750	63.26	.1522	.7182
	409.00	483.70	.2163	15	.9998	.4130	63.67	.1510	.5957
	409.04	483.58	.2161	10	.9941	.5450	63.55	.1513	.4547
	408.64	483.04	.2160	5	1.0094	.6720	63.27	.1530	.3295
	408.52	483.03	.2162	0	1.0351	.7770	62.74	.1548	.2292
	408.68	483.15	.2161	-5	.9956	.8690	62.15	.1583	.1333
	408.86	482.71	.2152	-10	.9801	.9370	61.12	.1635	.0485
	408.86	482.98	.2156	-15	.9644	.9620	59.66	.1705	-.0005
	408.41	525.49	.2636	25	.9253	.1740	63.26	.2097	.8117
	410.22	526.54	.2623	20	.9738	.3230	63.55	.2106	.6927
	410.63	527.33	.2626	15	.9963	.4590	63.65	.2126	.5505
	410.45	526.83	.2621	10	.9927	.6010	63.82	.2135	.4060
	410.56	526.84	.2622	5	.9955	.7150	63.35	.2170	.2556
	410.83	527.17	.2622	0	.9981	.8150	62.82	.2212	.1551
	410.27	527.05	.2628	-5	.9775	.8840	62.03	.2298	.0587
	410.06	526.98	.2630	-10	.9635	.9340	61.03	.2329	.0723
	410.61	527.41	.2627	-15	.9329	.9690	57.90	.2433	-.0334
	410.65	564.62	.2949	25	.9721	.2140	63.53	.2608	.7937
	410.11	563.23	.2944	20	.9935	.3590	64.04	.2580	.6699
	410.24	563.46	.2944	15	.9973	.5010	63.04	.2543	.5311
	410.79	564.32	.2945	10	1.0029	.6330	64.16	.2579	.3699
	410.36	563.67	.2945	5	1.0014	.7450	63.56	.2675	.2606
	410.54	564.31	.2948	0	1.0020	.8330	62.86	.2737	.1729
	410.47	564.42	.2949	-5	.9870	.9020	62.22	.2743	.0848
	410.63	564.76	.2950	-10	.9671	.9490	61.27	.2676	.0107
(J,54)	410.47	564.84	.2952	-15	.9372	.9830	59.76	.2637	-.0475

Table V. All Reduced Data From File ABNEW2.

COEFFICIENTS FOR THE CALIBRATION SURFACE STORED IN FILE MIS[illegible] : 26 Final

M(order) ↓ N(order) ⟶

M \ N	1	2	3	4	5
1	.058417	-.066206	.223789	-.568496	.729473
2	1.343718	.681829	-1.353865	6.966642	-5.[illegible]
3	-2.156698	-3.002923	-32.213394	14.260998	10.503395
4	-8.576551	85.379852	35.079987	-64.118652	12.651482
5	38.158485	-317.229310	435.952640	-382.115840	106.567090
	1	2	3	4	5

ERRORS AT EACH POINT

Mach Number		Pitch Angle → +25° 1	2	3	4	5	6	7	8	-15° 9
.2	1	-2.332	2.054	.039	.790	-.310	-1.182	.638	-.357	-1.439
	2	1.395	-.566	-1.149	-.499	.676	1.694	1.476	.808	.189
	3	-.150	-.415	-.261	.563	.241	-1.955	-1.274	-.317	-.366
	4	-.129	-.020	.757	.764	.122	-.051	.018	.450	.502
	5	.244	-.327	-.147	-.299	-.555	.046	.126	.965	-1.492
.7	6	.028	-.179	.290	.248	.035	-.088	-.474	.534	.355
		1	2	3	4	5	6	7	8	9

Table VI(a). Coefficients and Errors for Mach Number (X_{vel}) Approximation.

COEFFICIENTS FOR THE CALIBRATION SURFACE STORED IN FILE MIS[illegible] : 26 Final

M(order) ↓ N(order) ⟶

M \ N	1	2	3	4
1	-.774307	1.879133	-1.[illegible]	.154293
2	14.616833	-17.[illegible]	[illegible]	21.328826
3	-142.245970	100.[illegible]	[illegible]	-245.436950
4	520.891360	[illegible]	[illegible]	1138.825900
5	-858.544800	242.085800	-776.267800	-1743.12330
	1	2	3	4

ERRORS AT EACH POINT

Mach Number		Pitch Angle → +25° 1	2	3	4	5	6	7	8	-15° 9
.2	1	1.[illegible]	-1.510	.219	-.174	-.090	1.056	-.743	-.609	-.058
	2	-.381	.325	.269	-.164	.490	.248	.458	.311	.527
	3	-.048	-.560	.106	-.043	-.605	-.698	-.453	.073	-1.409
	4	-.116	.633	.359	.563	-1.526	.346	1.126	1.622	-.379
	5	-.209	.082	-.076	.010	-.189	.180	.123	-.562	-.215
.7	6	-.067	.284	-.072	-.300	.150	-.106	.327	-.163	.500
		1	2	3	4	5	6	7	8	9

Table VI(b). Coefficients and Errors for Pitch Angle (ϕ) Approximation.

CALCULATION			MEASUREMENT		ERRORS		
X Vel	Pitch	Yaw	X Vel	Pitch	X Vel	Pitch	Yaw
[ ]	[°]	[°]	[ ]	[°]	[%]	[°]	[°]
.1365	14.83	.69	.1347	15.00	-1.3357	.17	- .69
.1358	9.96	.52	.1349	10.00	- .6396	.04	- .52
.1343	5.03	.15	.1346	5.00	.2487	- .03	- .15
.1332	.07	.40	.1345	0.00	1.0161	- .07	- .40
.1766	14.75	.73	.1750	15.00	- .9074	.25	- .73
.1755	9.87	.71	.1758	10.00	.1439	.13	- .71
.1747	5.33	.68	.1750	5.00	.1923	- .33	- .68
.1751	.22	.53	.1751	0.00	.0256	- .22	- .53
.2155	14.04	.13	.2163	15.00	.3642	.96	- .13
.2161	9.09	.64	.2161	10.00	- .0087	.91	- .64
.2178	4.03	.80	.2160	5.00	- .8027	.97	- .80
.2182	- 1.36	1.05	.2162	0.00	- .9259	1.36	-1.05
.2643	15.36	.16	.2626	15.00	- .6210	- .36	- .16
.2635	10.56	.08	.2624	10.00	- .4118	- .56	- .08
.2639	4.02	.19	.2622	5.00	- .6578	.98	- .19
.2643	.54	.91	.2622	0.00	- .8000	- .54	- .91
.2960	15.20	1.01	.2944	15.00	- .5198	- .20	-1.01
.2968	10.64	.38	.2945	10.00	- .8086	- .64	- .38
.2978	5.03	.76	.2945	5.00	-1.1207	- .03	- .76
.2944	.41	1.16	.2948	0.00	.1303	- .41	-1.16
				Averages:	-0.3717	+ 0.119	-0.504

Table VII. Errors in Mach Number, Pitch and Yaw Angle for the Application of Calibration Procedure to Calibration Raw Data.

CALCULATED FROM MEASURED DATA			ADJUSTED FREEJET VALUES			ERRORS		
X Vel	Pitch	Yaw	X Vel	Pitch	Yaw	X Vel	Pitch	Yaw
[ ]	[°]	[°]	[ ]	[°]	[°]	[ ]	[°]	[°]
.14206	.04	0.31	.1420	0	0	-0.04	-0.04	-0.31
.14373	4.74	-0.11	.1459	5	0	+1.49	-0.26	+0.11
.14368	4.79	0.1	.1459	5	0	+1.52	+0.21	-0.1
.14315	10.18	0.24	.1450	10	0	+1.28	-0.18	-0.24
.14483	14.82	- 0.3	.1448	15	0	-0.02	+0.18	+0.30
.16787	9.78	0.78	.170	10	0	+1.22	+0.22	-0.78
.17199	8.97	5.46	.170	10	5	-1.17	+1.03	-0.45
.17053	10.20	10.22	.170	10	10	-0.31	-0.2	-0.22
.20382	7.66	- 0.18	.2049	7	0	+0.53	-0.66	+0.18
.21165	10.16	0.2	.211	10	0	-0.31	-0.16	-0.2
.20467	13.21	0.24	.2052	13	0	+0.26	-0.21	-0.24

Table VIII. Errors in Mach Number, Pitch and Yaw Angle for A-B Probe Application Test in Freejet.

( )	(°)	( )
.0958	25	.0030
.0962	20	.1470
.0961	15	.2790
.0960	10	.4250
.0962	5	.5680
.0965	0	.6930
.0965	- 5	.7860
.0963	-10	.8470
.0954	-15	.9040
.1348	25	.0460
.1348	20	.1970
.1347	15	.3320
.1349	10	.4760
.1346	5	.6080
.1345	0	.7290
.1353	- 5	.8240
.1343	-10	.8900
.1349	-15	.9190
.1754	25	.0930
.1752	20	.2400
.1750	15	.3810
.1758	10	.5160
.1750	5	.6390
.1751	0	.7480
.1744	- 5	.8510
.1744	-10	.9200
.1742	-15	.9520
.2171	25	.1290
.2165	20	.2750
.2163	15	.4130
.2161	10	.5480
.2160	5	.6720
.2162	0	.7770
.2161	- 5	.8690
.2152	-10	.9370
.2156	-15	.9620
.2636	25	.1740
.2624	20	.3230
.2626	15	.4590
.2624	10	.6010
.2622	5	.7150
.2622	0	.8150
.2628	- 5	.8860
.2630	-10	.9340
.2627	-15	.9690
.2949	25	.2140
.2944	20	.3590
.2944	15	.5010
.2945	10	.6330
.2945	5	.7450
.2948	0	.8330
.2948	- 5	.9020
.2950	-10	.9490
.2952	-15	.9830

Table IX. CpOB for All Calibration Configurations of Mach Number and Pitch A

Point #	Immer.comb. / Immer.A pr. / Immer.B pr.	yaw comb. / yaw A pr. / yaw B pr.	P1 / DCA / DCB	P23 / Pref / RPM	P4 / T* / DT*
1	.000897	.003079	.000369	.000062	.000003
	.000901	.003127	.000023	.000369	.000727
	.000909	.003085	-.001729	1524.00000	[illegible]
2	.000900	.003057	.000372	.000058	.000003
	.000902	.003128	-.001640	.000530	[illegible]
	.000911	.003097	-.003348	1524.00000	.000692
3	.000901	.003110	.000369	.000065	.000102
	.000903	.003123	.006186	-.000245	.000727
	.000909	.003090	.004634	1524.00000	.000675
4	.000901	.003108	.000371	.000056	.000097
	.000901	.003129	.003722	.000002	[illegible]
	.000911	.003096	.002112	1525.00000	.000678

Online calibration (File : A0119[illegible])

Point #	Immer.comb. / Immer.A pr. / Immer.B pr.	yaw comb. / yaw A pr. / yaw B pr.	P1 / DCA / DCB	P23 / Pref / RPM	P4 / T* / DT*
1	.000901	.003063	.000378	.000060	.000030
	.000902	.003031	.003704	0.000000	[illegible]
	.000911	.003098	.002926	1525.00000	[illegible]
2	.000901	.003115	.000379	.000061	.000019
	.000902	.003091	-.001584	.000532	.000707
	.000915	.003098	-.004333	1525.00000	.000648
3	.000902	.003093	.000382	.000068	[illegible]
	.000903	.003084	.006207	-.000246	[illegible]
	.000913	.003101	.004708	1525.00000	[illegible]
4	.000903	.003104	.000378	.000057	[illegible]
	.000902	.003082	.000649	.000323	[illegible]
	.000910	.003079	-.001673	1525.00000	.000678

	A probe Slope	Intercept		P probe Slope	Intercept
1st calibration	-.099068	.000370	*	-.096795	[illegible]
2nd calibration	-.100253	.000375	*	-.097386	[illegible]

ble X(a). On-line Calibration Data for Actual Compressor Test (run #119).

Point #	Immer. comp. / Immer. A pr. / Immer. B pr.	yaw comp. / yaw A pr. / yaw B pr.	P1 / DCA / DCB	P23 / Pref / RPM	[illegible]
	.000901	.003047	.000372	.000064	.0000[illegible]
1	.000903	-.004006	-.001234	.000003	.000[illegible]
	.000913	-.003985	-.002172	1526.00000	.000[illegible]
Averaged values paced output :		A probe :	-.12831	B probe :	-.227[illegible]
	.000902	.003060	.000372	.000065	.00001[illegible]
2	.000912	-.002004	.001488	.000002	.00072[illegible]
	.000911	-.001975	-.000020	1527.00000	.00068[illegible]
Averaged values paced output :		A probe :	.15864	B probe :	-.00521
	.000901	.003110	.000374	.000063	.00002[illegible]
3	.000903	-.000037	.003700	.000003	.00072[illegible]
	.000912	0.000010	.001223	1527.00000	00067[illegible]
Averaged values paced output :		A probe :	.33133	B probe :	.13341
	.000901	.003050	.000369	.000067	.00000[illegible]
4	.000902	.001471	.003721	.000001	.0007[illegible]
	.000913	.001592	.001961	1527.00000	.00069[illegible]
Averaged values paced output :		A probe :	.37954	B probe :	.12969
	.000900	.003080	.000376	.000063	.00000[illegible]
5	.000902	.002970	.003750	.000003	.000688
	.000908	.002979	.002069	1527.00000	.000678
Averaged values paced output :		A probe :	.38385	B probe :	.21974
	.000900	.003023	.000376	.000074	.000019
6	.000901	.004466	.003570	.000002	.000692
	.000911	.004509	.001206	1528.00000	.000665
Averaged values paced output :		A probe :	.37362	B probe :	.19992
	.000899	.003494	.000373	.000064	.00000[illegible]
7	.000901	.006499	.002857	0.000009	.000690
	.000909	.006533	.001204	1528.00000	.000671
Averaged values paced output :		A probe :	.30029	B probe :	.11550
	.000903	.003093	.000371	.000073	.00001[illegible]
8	.000904	.008477	.001169	.000001	.00069[illegible]
	.000912	.008524	-.000529	1527.00000	.000687
Averaged values paced output :		A probe :	.12077	B probe :	-.05694
	.000900	.003074	.000375	.000062	.000005
9	.000901	.010957	-.002386	1.000000	.000699
	.000910	.011028	-.003602	1526.00000	.000680
Averaged values paced output :		A probe :	-.22715	B probe :	-.36723

Table X(b). Run Steady State Data From A-B Probe Measurement (run #119).

DATA ARRANGEMENT IN DATA FILE FOR RAW DATA FROM KULITE SURVEY
DATA(20,256)

CALIBRATION POINT			1st YAW A	1st YAW B	2nd YAW A	2nd YAWB	---	9th YAW A	9th YAW B	STEADY STATE yaw	
DATA(1, 1)	1	1st	DATA(2, 1)	DATA(3, 1)	DATA(4, 1)	DATA(5, 1)	---	DATA(18, 1)	DATA(19, 1)	DATA(20, 1)	1st
DATA(1, 2)			DATA(2, 2)	DATA(3, 2)	DATA(4, 2)	DATA(5, 2)	---	DATA(18, 2)	DATA(19, 2)	DATA(20, 2)	
DATA(1, 3)			DATA(2, 3)	DATA(3, 3)	DATA(4, 3)	DATA(5, 3)	---	DATA(18, 3)	DATA(19, 3)	DATA(20, 3)	
:			:	:	:	:		:	:	:	
DATA(1, 19)			:	:	:	:		:	:	DATA(20, 20)	
DATA(1, 21)	2		:	:	:	:		:	:	DATA(20, 21)	2nd
DATA(1, 22)			:	:	:	:		:	:	DATA(20, 22)	
:			:	:	:	:		:	:	:	
DATA(1, 38)			:	:	:	:		:	:	DATA(20, 40)	
DATA(1, 41)	3									DATA(20, 41)	3rd
DATA(1, 42)										DATA(20, 42)	
:										:	
DATA(1, 58)										DATA(20, 60)	
DATA(1, 61)	4									DATA(20, 61)	4th
DATA(1, 62)										DATA(20, 62)	
:										:	
DATA(1, 78)										DATA(20, 80)	
DATA(1, 81)	1	2nd								DATA(20, 81)	5th
DATA(1, 82)										DATA(20, 82)	
:										:	
DATA(1, 98)			:	:	:	:		:	:	DATA(20, 100)	
DATA(1,101)	2		:	:	:	:		:	:	DATA(20,101)	6th
DATA(1,102)			:	:	:	:		:	:	DATA(20,102)	
:			:							:	
DATA(1,118)			:							DATA(20,120)	
DATA(1,121)	3		:							DATA(20,121)	7th
DATA(1,122)			:							DATA(20,122)	
:			:							:	
DATA(1,138)			:							DATA(20,140)	
DATA(1,141)	4		:							DATA(20,141)	8th
DATA(1,142)			:							DATA(20,142)	
:			:							"	
DATA(1,158)			:							DATA(20,160)	
DATA(1,160) Slope A 1st			:							DATA(20,161)	9th
DATA(1,161) Inter.A 1st			:							DATA(20,162)	
DATA(1,170) Slope B 1st			:	:	:	:		:	:	"	
DATA(1,171) Inter.B 1st			:	:	:	:		:	:	DATA(20,180)	
DATA(1,180) Slope A 2nd			:	:	:	:		:	:	---	
DATA(1,181) Inter.A 2nd			:	:	:	:		:	:	---	
DATA(1,190) Slope B 2nd			:	:	:	:		:	:	---	
DATA(1,191) Inter.B 2nd			:	:	:	:		:	:	---	
---			:	:	:	:		:	:	---	
---			:	:	:	:		:	:	---	
			DATA(2,256)	DATA(3,256)	DATA(4,256)	DATA(5,256)	---	DATA(18,256)	DATA(19,256)	---	

J=1, 21, 41, 61, 81 ... 141
Data for online calibration

```
DATA(1,J   ) = TARE2 = ACON ( 4, 1,10)
DATA(1,J+ 1) = PCAL2 = ACON ( 4, 2,10)
DATA(1,J+ 2) = P1    = ACON ( 4, 6,10)
DATA(1,J+ 3) = P23   = ACON ( 4, 7,10)
DATA(1,J+ 4) = P4    = ACON ( 4, 8,10)
DATA(1,J+ 5) = RPM   = SCANR( 8,17, 2)
DATA(1,J+ 6) = PBARO = SCANR( 8,25, 1)
DATA(1,J+ 7) = XIMC  = SCANR( 8,32, 1)
DATA(1,J+ 8) = YAWC  = SCANR( 8,33, 1)
DATA(1,J+ 9) = XIMA  = SCANR( 8,34, 1)
DATA(1,J+10) = YAWA  = SCANR( 8,35, 1)
DATA(1,J+11) = XIMB  = SCANR( 8,36, 1)
DATA(1,J+12) = YAWB  = SCANR( 8,37, 1)
DATA(1,J+13) = PREF  = SCANR( 8,39, 1)
DATA(1,J+14) = E     = SCANR(15,18, 1)
DATA(1,J+15) = DE    = SCANR(15,19, 1)
DATA(1,J+16) = DCA   = SCANR(15,52, 1)
DATA(1,J+17) = DCB   = SCANR(15,53, 1)
```

I = 1, 21, 41 161
Data for steady state

```
DATA(20,I   ) = ACON ( 4, 1,10)  TARE2
DATA(20,I+ 1) = ACON ( 4, 2,10)  PCAL2
DATA(20,I+ 2) = ACON ( 4, 6,10)  P1
DATA(20,I+ 3) = ACON ( 4, 7,10)  P23
DATA(20,I+ 4) = ACON ( 4, 8,10)  P4
DATA(20,I+ 5) = SCANR( 8,17, 2)  RPM
DATA(20,I+ 6) = SCANR( 8,25, 1)  PBARO
DATA(20,I+ 7) = SCANR( 8,32, 1)  XIMC
DATA(20,I+ 8) = SCANR( 8,33, 1)  YAWC
DATA(20,I+ 9) = SCANR( 8,34, 1)  XIMA
DATA(20,I+10) = SCANR( 8,35, 1)  YAWA
DATA(20,I+11) = SCANR( 8,36, 1)  XIMB
DATA(20,I+12) = SCANR( 8,37, 1)  YAWB
DATA(20,I+13) = SCANR( 8,39, 1)  PREF
DATA(20,I+14) = SCANR(15,18, 1)  E
DATA(20,I+15) = SCANR(15,19, 1)  DE
DATA(20,I+16) = SCANR(15,52, 1)  DCA
DATA(20,I+17) = SCANR(15,53, 1)  DCB
DATA(20,I+18) = AVRGA
DATA(20,I+19) = AVRGB
```

Table XI. Arrangement of Data Within Raw Data File.

```
**************************************************
RAW DATA FILE : AB1901:: 27
**************************************************

FLOW AVARAGED VALUES AS ESTABLISHED WITH THE COMBINATION PROBE

 Ptotal(INCH H2O) Pstatic(INCH H2O)      Xvel      Mach  Phi(deg)  Yaw(deg)
       438.852110          402.299380    .15693    .35443      4.55     30.76

EQUATION FOR A-PROBE PRESSURE :
PA =   400.532230 +  9966.041000 * VOLTAGE(raw)*0.01 + PREF(INCH H2O)
CP0A =     1.00408 CP0B =     .6394757
EQUATION FOR B-PROBE PRESSURE :
PB =   405.349850 +  9709.025400 * VOLTAGE(raw)*0.01 + PREF(INCH H2O)

#  PAA(#)  PAB(#) YAWA(#) YAWB(#)

1 388.564 384.562 -40.060 -39.850
2 415.562 405.356 -20.040 -19.750
3 432.724 417.524 -.37000 0.00000
4 438.413 424.489 14.7100 15.0200
5 438.205 425.738 29.7000 29.7900
6 436.311 424.055 44.6600 45.0900
7 429.005 417.040 64.9900 65.3300
8 412.283 400.314 84.7900 85.2400
9 376.753 370.378 109.570 110.280
A-PROBE APPROXIMATION RESULTS : YAW =          -32.03          30.97        9
                PRESSURE (INCH H2O) =      401.494630     438.987430    401.49
                             CPAMAX =    1.0036

B-PROBE APPROXIMATION RESULTS : YAW0 =  31.1 PRESSURE  (INCH H2O) =426.03

AVERAGE VALUE RESULTS FROM THE A-B SYSTEM:

    BETA     GAMMA     Xvel    Pitch       Yaw        XU       XAX     BETA2
  .08541    .34569   .15693     4.00     31.13    .24251    .13400     50.33


A-PROBE APPROXIMATION RESULTS : YAW =          -33.87          29.13        9
                PRESSURE (INCH H2O) =      401.035520     439.204830    401.03
                             CPAMAX =    1.0093

#   YAWA(I)     PA(I)     PAC(I)       DPA   YAWB(I)     PB(I)    PBC(I)
1   -40.060   390.745   390.620    .12415   -39.850   386.023   386.211   -.
2   -20.040   418.046   418.693   -.64673   -19.750   407.238   406.601    .
3   -.37000   434.472   433.312   1.16040   0.00000   419.654   420.214   -.
4   14.7100   438.073   438.307   -.23431   15.0200   425.849   426.014   -.
5   29.7000   438.365   439.171   -.80560   29.7900   427.988   427.737    .
6   44.6600   436.436   436.487   -.05164   45.0900   425.091   425.287   -.
7   64.9900   428.007   427.055    .95190   65.3300   416.069   415.419    .
8   84.7900   409.352   409.953   -.60059   85.2400   397.940   398.495   -.
9   109.570   372.605   372.503    .10175   110.280   367.713   367.588    .
B-PROBE APPROXIMATION RESULTS : YAW0 =  28.8 PRESSURE  (INCH H2O) =427.75

 PSTATIC (DERIVED FROM PAMAX AND XVEL) =  402.086



POS#      Beta     Gamma      Xvel     Pitch       Yaw     BETA2
  1     .08691    .30020    .15784      2.16     28.77     50.31
```

Table XII. Explicit Output of Reduced Data (run #119).

Raw Data From File AB1901:27.

POS#	Beta	Gamma	Xvel	Pitch	Yaw	BETA2
1	.08691	.30020	.15784	2.16	28.77	50.31
2	.08625	.29869	.15719	2.07	28.85	50.47
3	.08659	.29771	.15751	2.04	28.77	50.39
4	.08693	.29870	.15785	2.10	28.67	50.32
5	.08626	.29383	.15714	1.86	28.34	50.54
6	.08556	.29333	.15646	1.81	27.89	50.78
7	.08761	.29336	.15845	1.89	27.95	50.27
8	.08695	.29314	.15780	1.86	27.77	50.46
9	.08699	.30001	.15792	2.16	27.87	50.42
10	.08651	.29053	.15735	1.72	28.18	50.51
11	.08616	.30175	.15714	2.20	27.01	50.75
12	.08771	.30535	.15867	2.41	27.27	50.32
13	.08736	.31543	.15844	2.83	27.40	50.38
14	.08758	.31300	.15863	2.74	27.95	50.24
15	.08843	.31647	.15949	2.91	27.52	50.10
16	.08708	.32767	.15832	3.33	27.13	50.47
17	.08815	.33026	.15937	3.48	27.70	50.12
18	.08751	.33647	.15883	3.71	27.75	50.26
19	.08845	.34354	.15981	4.03	27.49	50.07
20	.08694	.35824	.15855	4.57	27.79	50.37
21	.08777	.35549	.15931	4.49	28.23	50.11
22	.08727	.35913	.15888	4.61	27.57	50.32
23	.08724	.36278	.15890	4.76	28.06	50.25
24	.08730	.36500	.15898	4.85	28.28	50.20
25	.08809	.35980	.15967	4.67	28.19	50.03
26	.08817	.35931	.15973	4.65	27.69	50.09
27	.08765	.36770	.15935	4.97	28.86	50.03
28	.08754	.37437	.15933	5.22	28.31	50.13
29	.08721	.35432	.15876	4.42	28.80	50.16
30	.08759	.36250	.15923	4.76	29.11	50.02
31	.08590	.34610	.15741	4.04	29.45	50.41
32	.08591	.33789	.15732	3.71	29.74	50.38
33	.08682	.34274	.15825	3.94	28.54	50.30
34	.08629	.33269	.15762	3.51	28.85	50.40
35	.08633	.33968	.15774	3.80	28.47	50.44
36	.08652	.33720	.15789	3.70	29.09	50.31
37	.08466	.32843	.15600	3.27	28.94	50.81
38	.08430	.32945	.15566	3.29	28.62	50.94
39	.08466	.31729	.15586	2.80	28.75	50.85
40	.08445	.31319	.15561	2.62	29.15	50.86
41	.08548	.31905	.15668	2.91	28.62	50.66
42	.08583	.32284	.15706	3.08	27.88	50.67
43	.08569	.31942	.15688	2.93	28.83	50.58
44	.08616	.31527	.15729	2.78	28.39	50.53
45	.08673	.32951	.15801	3.39	29.01	50.28
46	.08768	.32712	.15888	3.33	28.90	50.06
47	.08778	.32402	.15894	3.21	28.34	50.12
48	.08757	.32691	.15878	3.32	29.08	50.07
49	.08892	.31918	.15998	3.04	28.51	49.82
50	.08780	.32379	.15897	3.20	28.24	50.13
51	.08746	.32749	.15868	3.34	28.18	50.22
52	.08814	.31063	.15914	2.65	28.43	50.04

Table XIII. Reduced Data For the First Blade Passage of Run #119.

Range of Xvel	Range of Pitch	Range of Yaw	E_x[%]	E_ϕ[°]	E_α[°]
$0.134 \leq X \leq 0.216$	$0 \leq \phi \leq 10$	$-10 \leq \alpha \leq 10$	-4.6	0.78	-0.93
$0.134 \leq X \leq 0.216$	$5 \leq \phi \leq 15$	$-10 \leq \alpha \leq 10$	-4.7	0.96	-0.77
$0.175 \leq X \leq 0.263$	$0 \leq \phi \leq 10$	$-10 \leq \alpha \leq 10$	6.0	0.50	-0.65
$0.175 \leq X \leq 0.263$	$5 \leq \phi \leq 15$	$-10 \leq \alpha \leq 10$	-5.0	0.66	-0.57

Table XIV. Errors in Mach Number, Pitch and Yaw Angle for Varying Velocity Vectors.

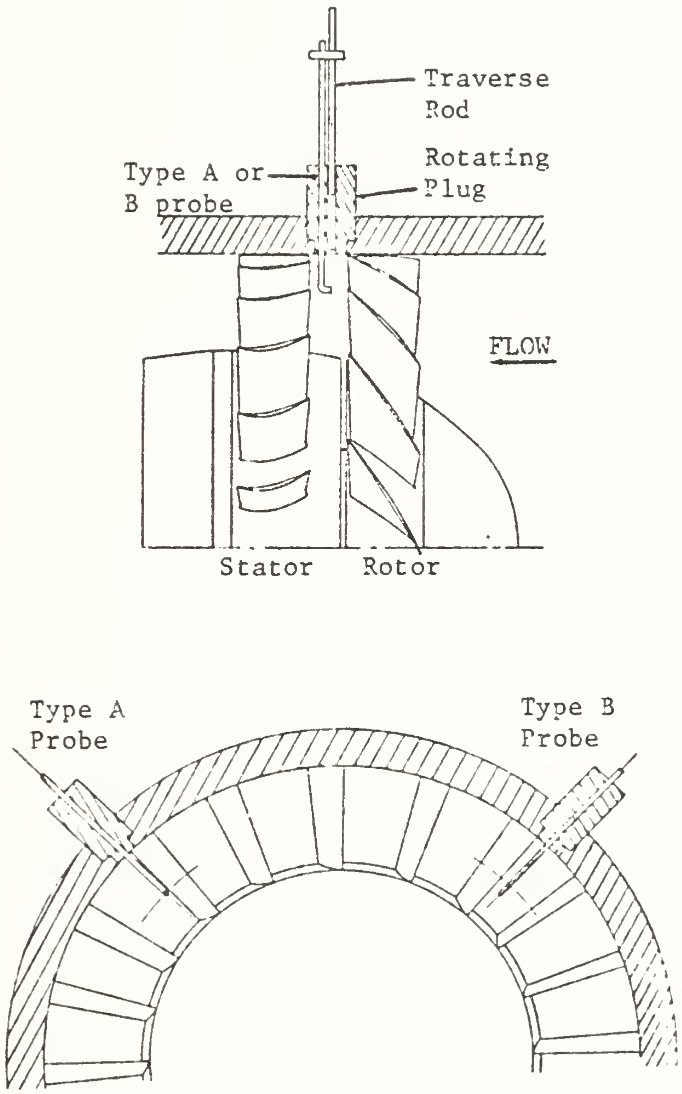


Figure 1. Probe Arrangement in Transonic Compressor

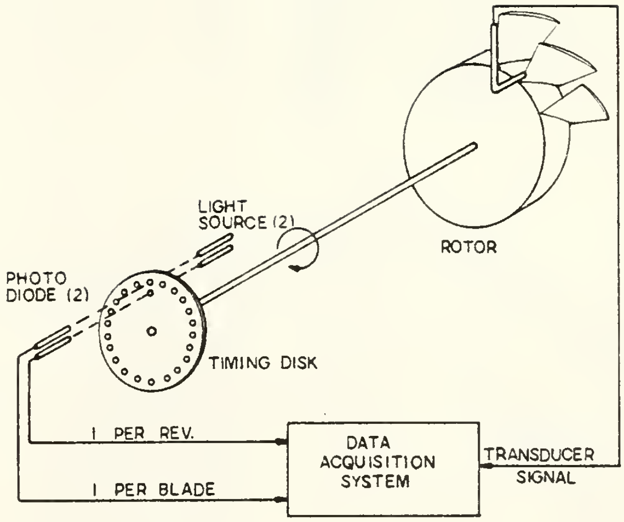


Figure 2. Controlled (Paced) Sampling Technique

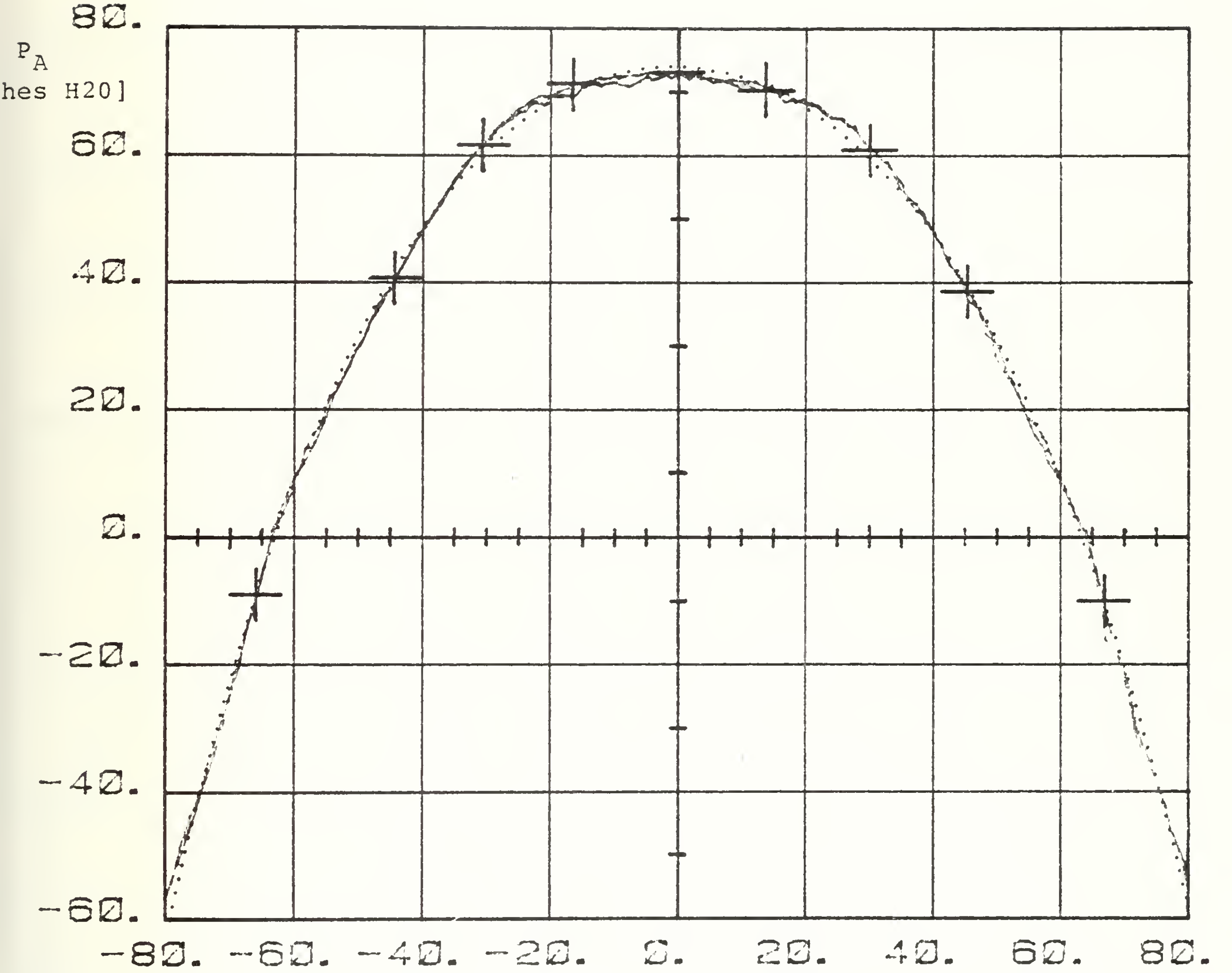


Figure 3a. A-Probe Pressure (Gauge) vs. Yaw Angle
Solid line - Calibration Data
Dotted line - Data Approximated from Specific Data Points (4th Order Polynomials) Shown as crosses
(Datafile: A5KP10)

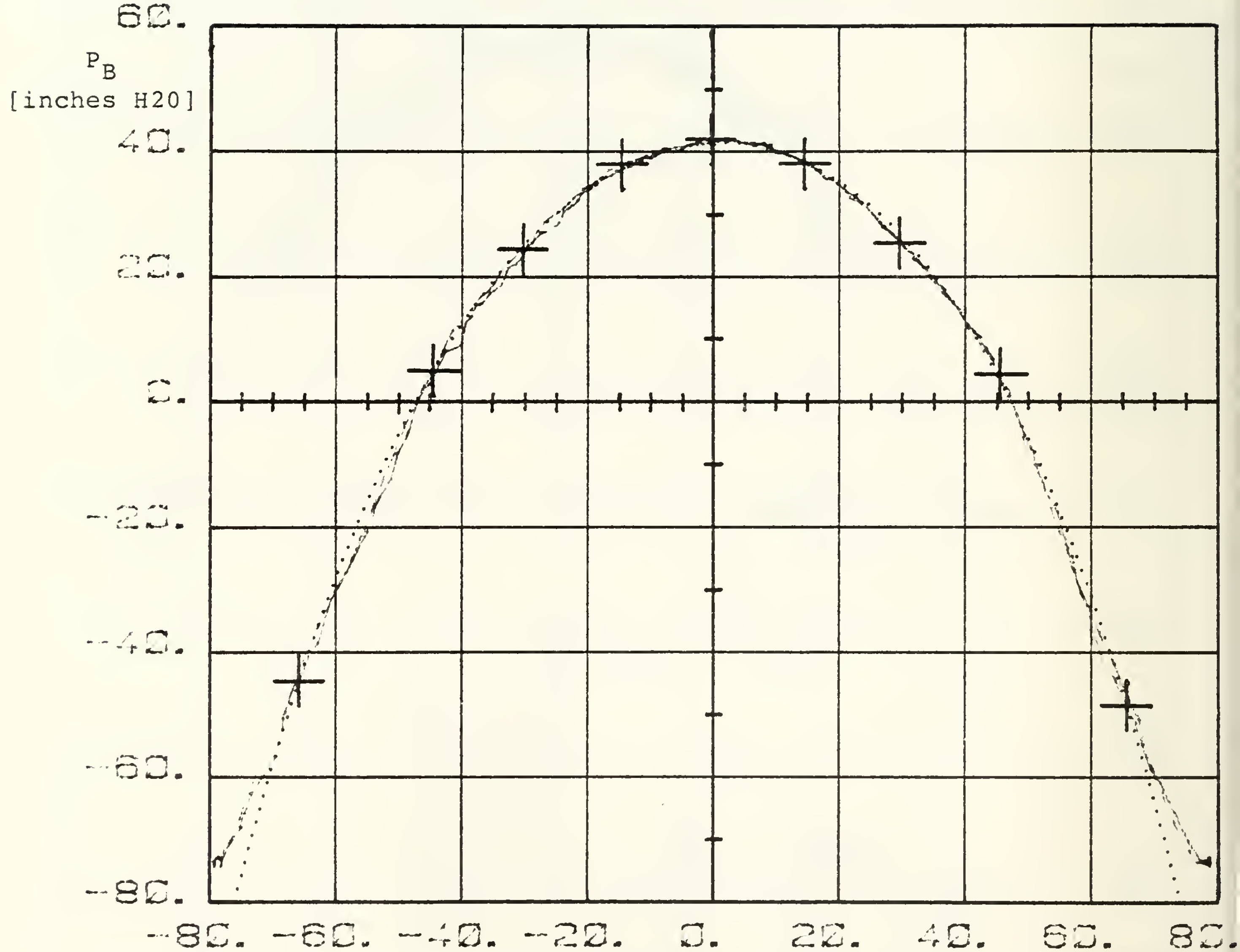


Figure 3b. B-Probe Pressure (Gauge) vs. Yaw Angle
Solid line - Calibration Data
Dotted line - Data Approximated from Specific Data Points (4th Order Polynomials) Shown as crosses (Datafile: B5KP10)

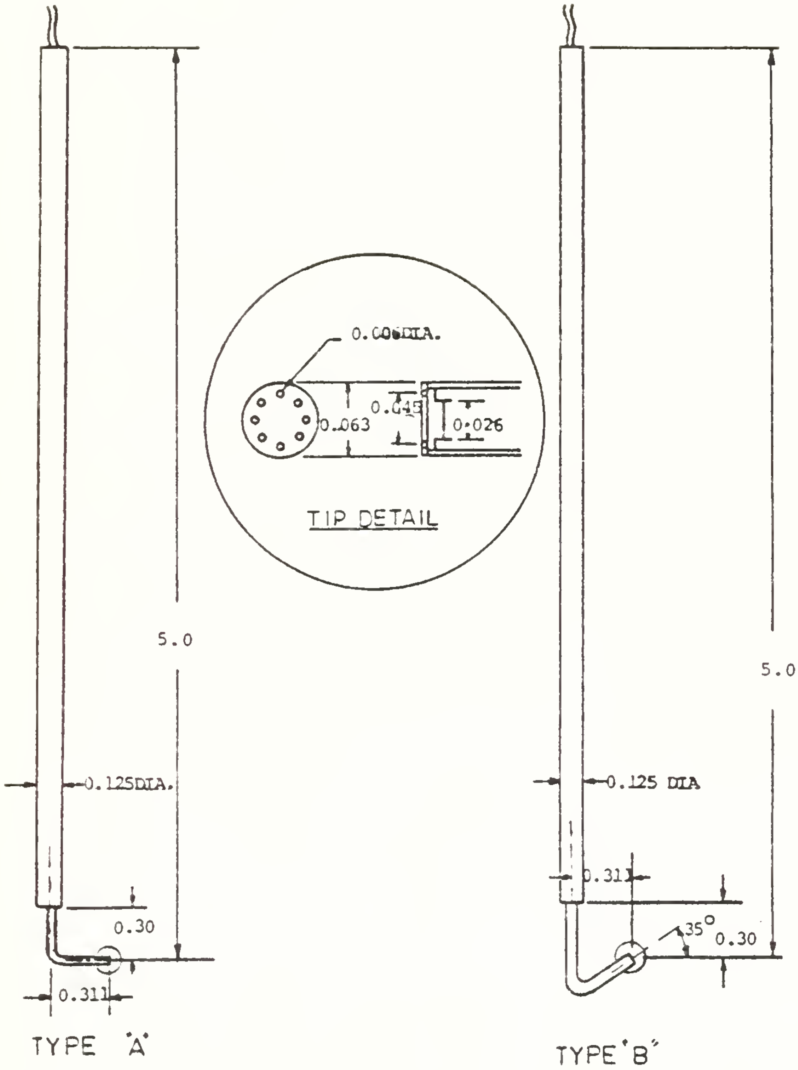


Figure 4. High Response Transducer Probes

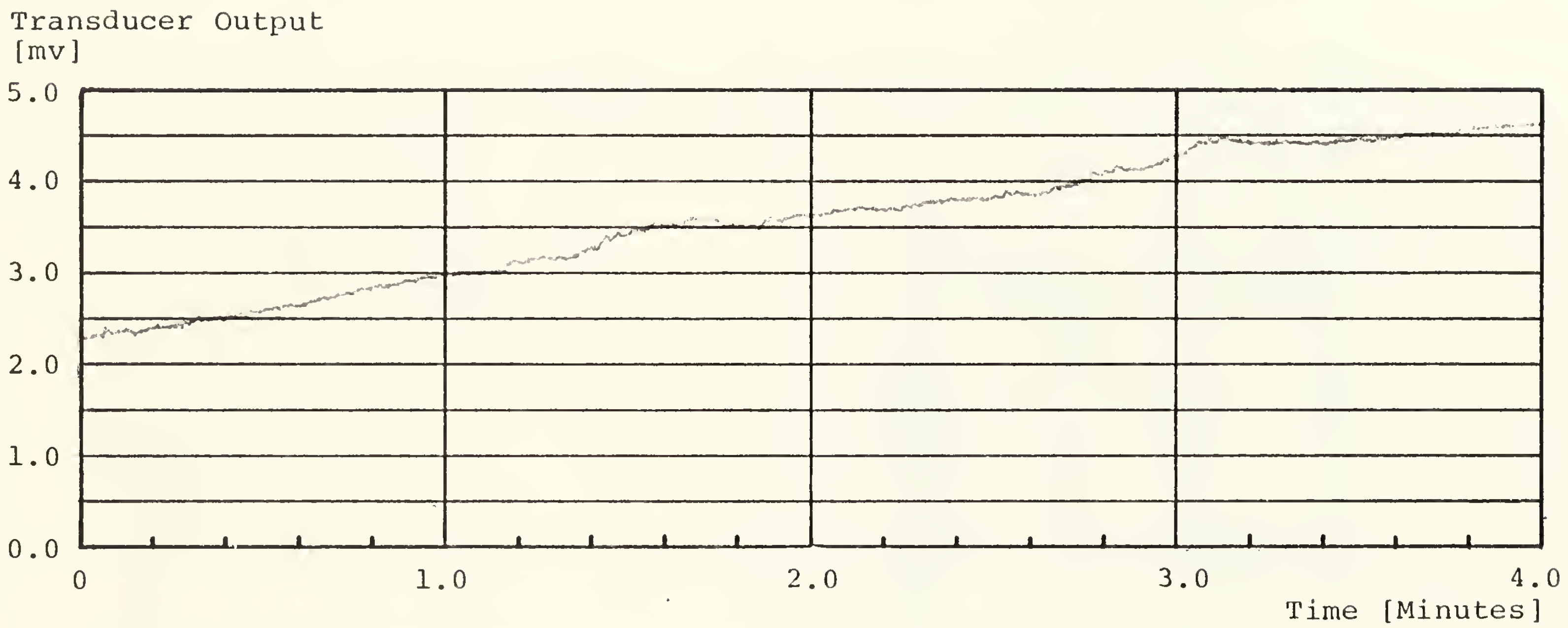


Figure 5. Temperature Sensitivity of a Kulite-Transducer
Calibrated to: lmv Equivalent to 1 Inch of Water (Gauge)
4 Minutes Equivalent to 1000 Single Samples

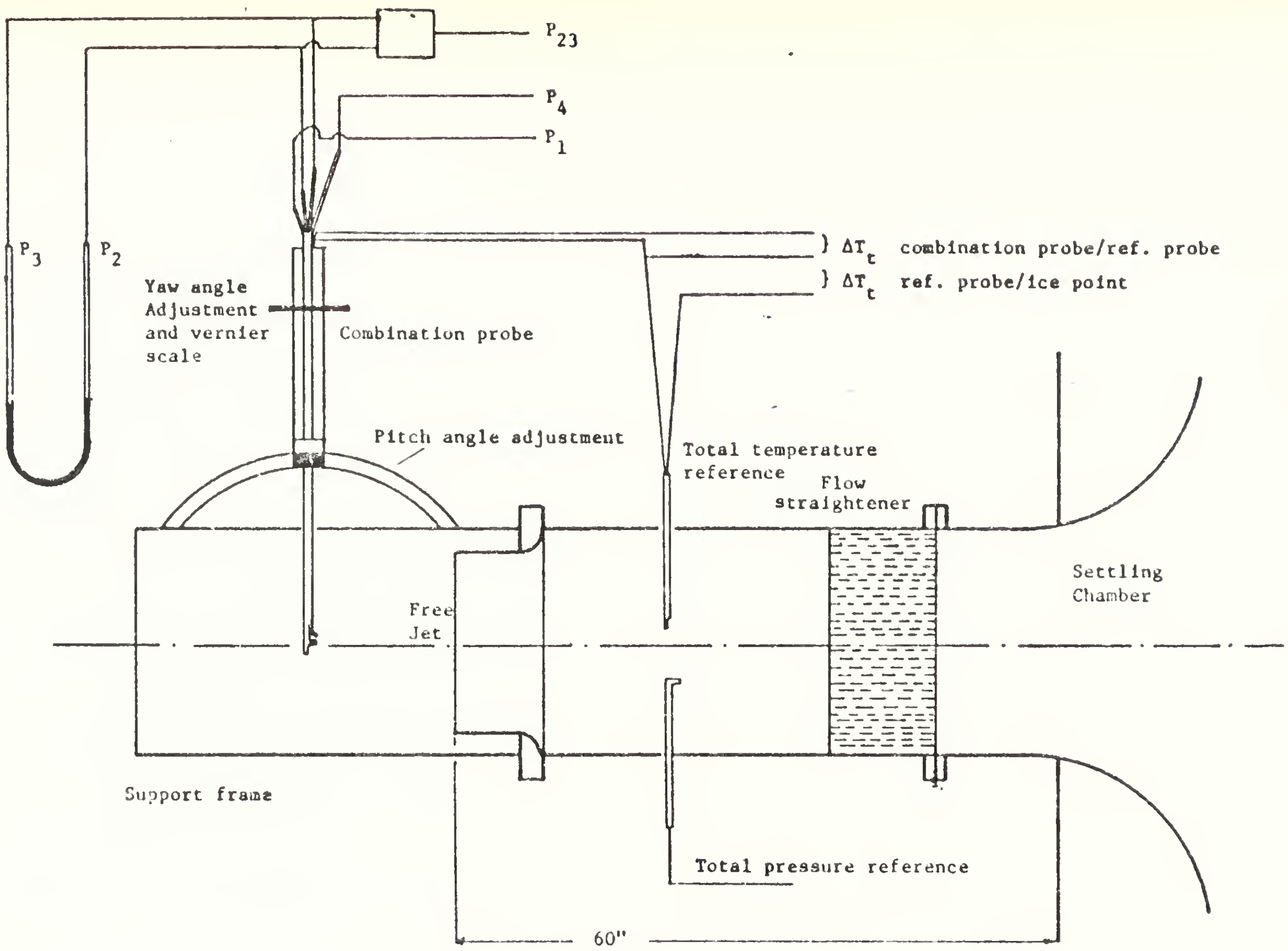
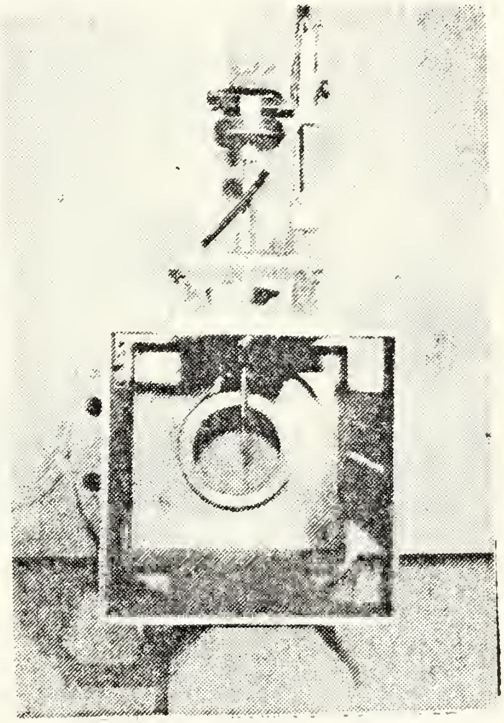
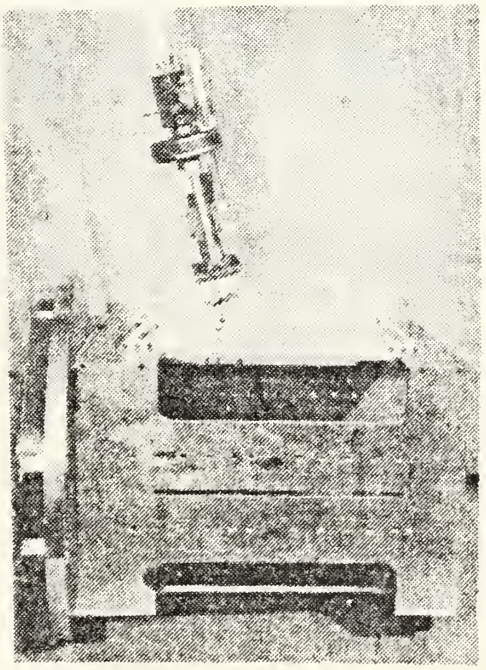


Figure 6a. Calibration Facility Geometry (not to scale)



(a) End View



(b) Side View

Figure 6b. Free-Jet Calibration Apparatus

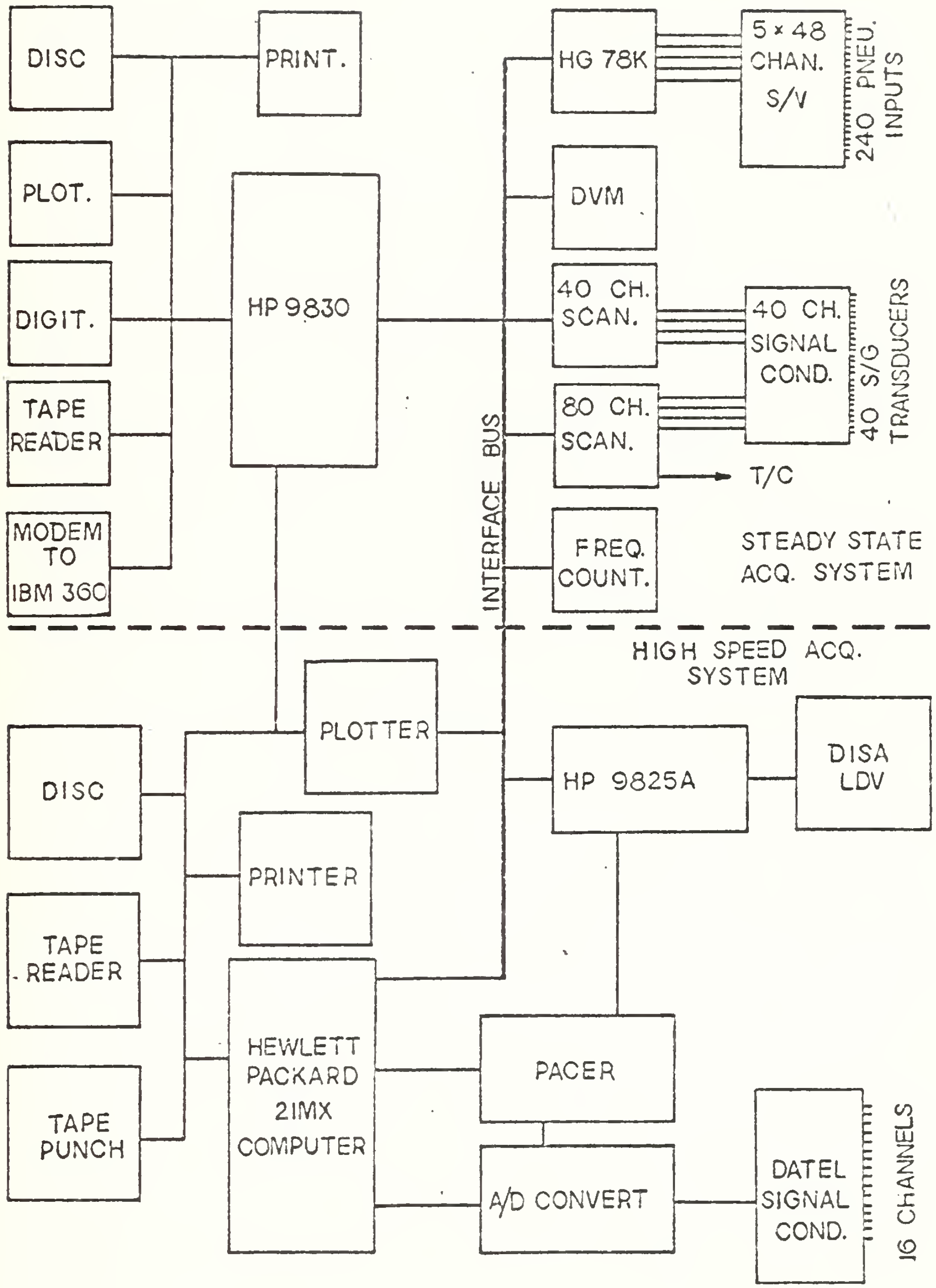


Figure 6c. Data Acquisition System

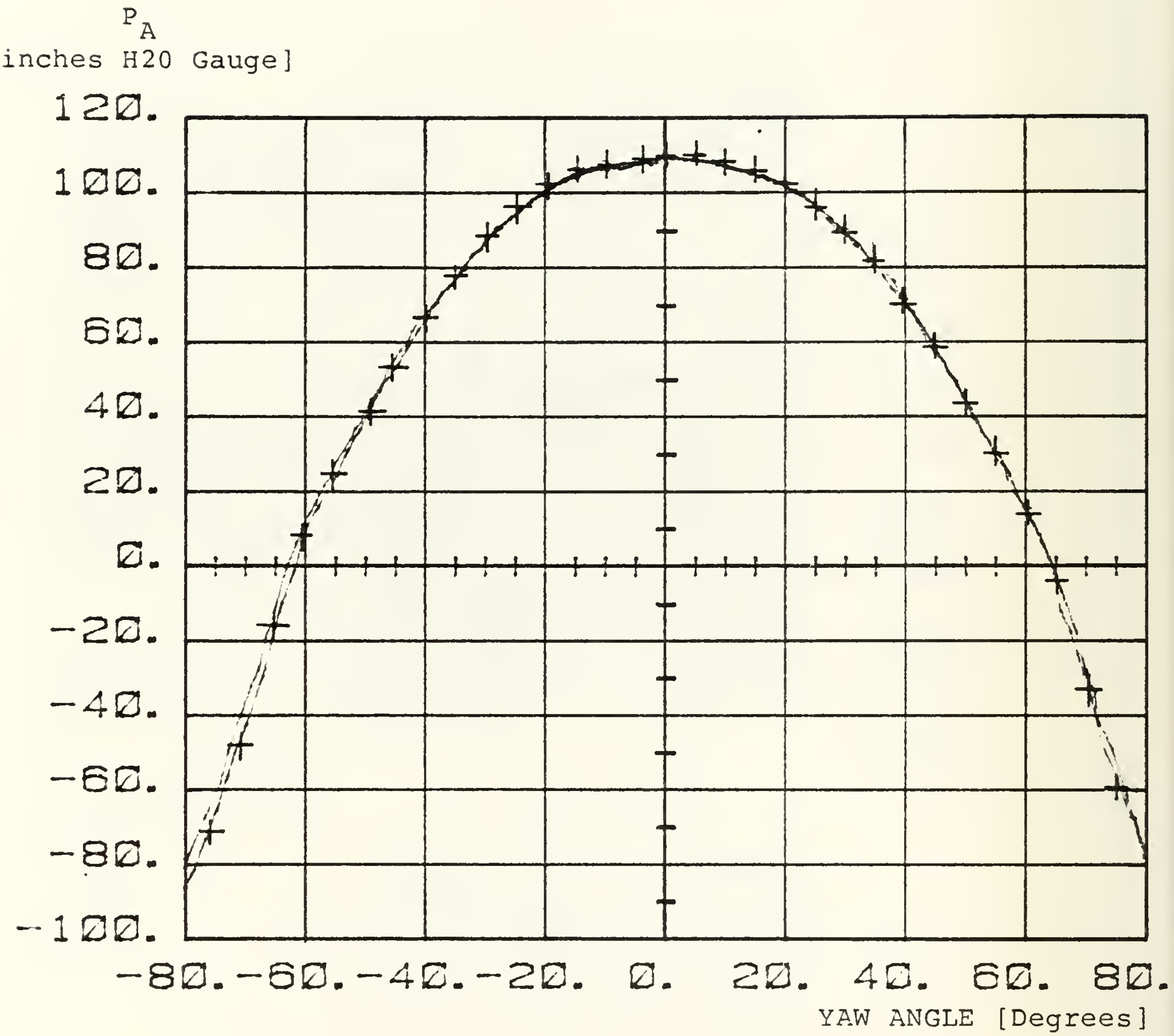


Figure 7. Pressure Readings vs. Yaw Angle. Data Acquired Using Two Different Programs:
Solid lines - Program KALIB (Continuous Acquisi
Crosses - Program &YAW (Discrete Readings)

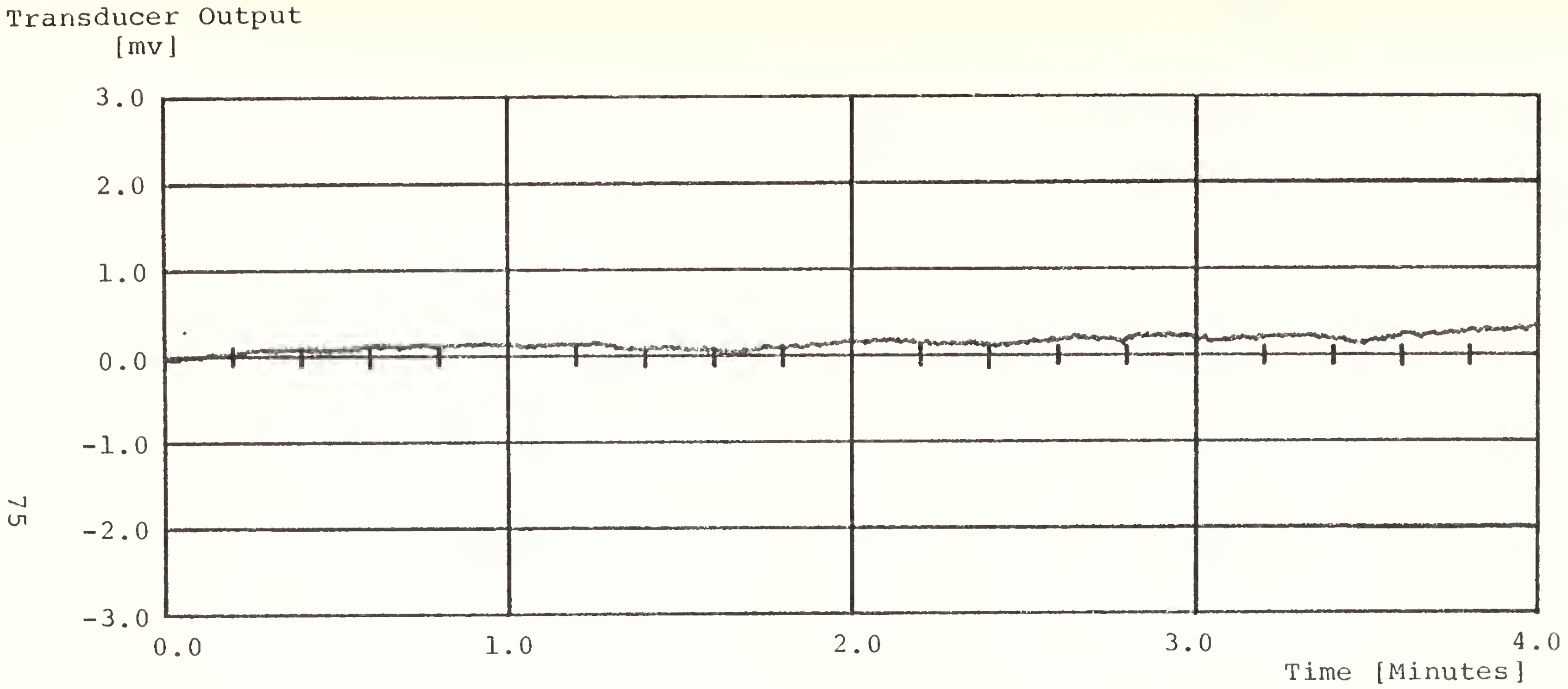


Figure 8. Kulite Transducer Output Depending on Time, No Change in Environment. Calibrated to: 1mv Equivalent to 1 inch of Water.

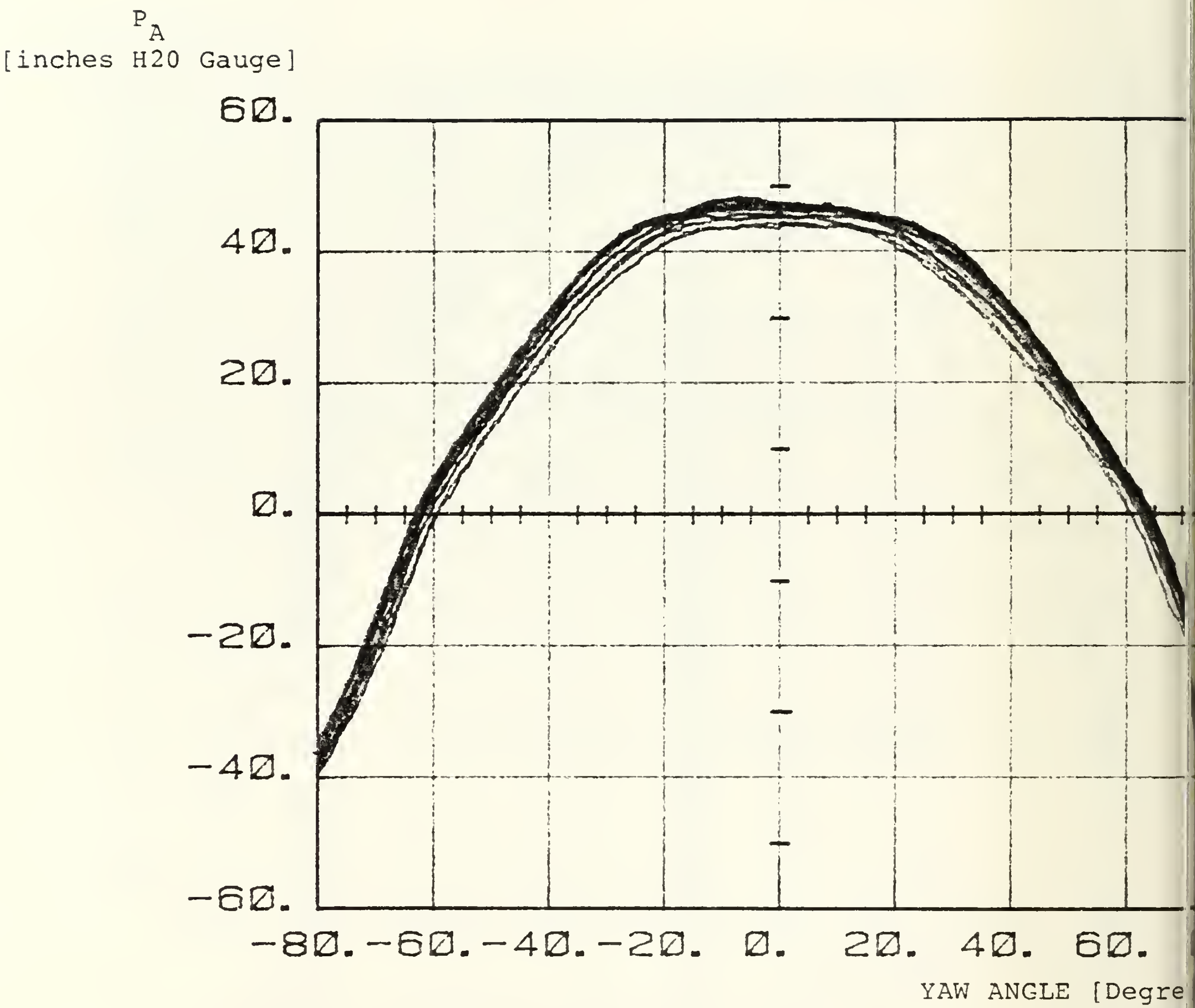


Figure 9. Type A-Probe Calibration Data at Mach = 0.4. Pitch Angles in the Range from -15° to +25°

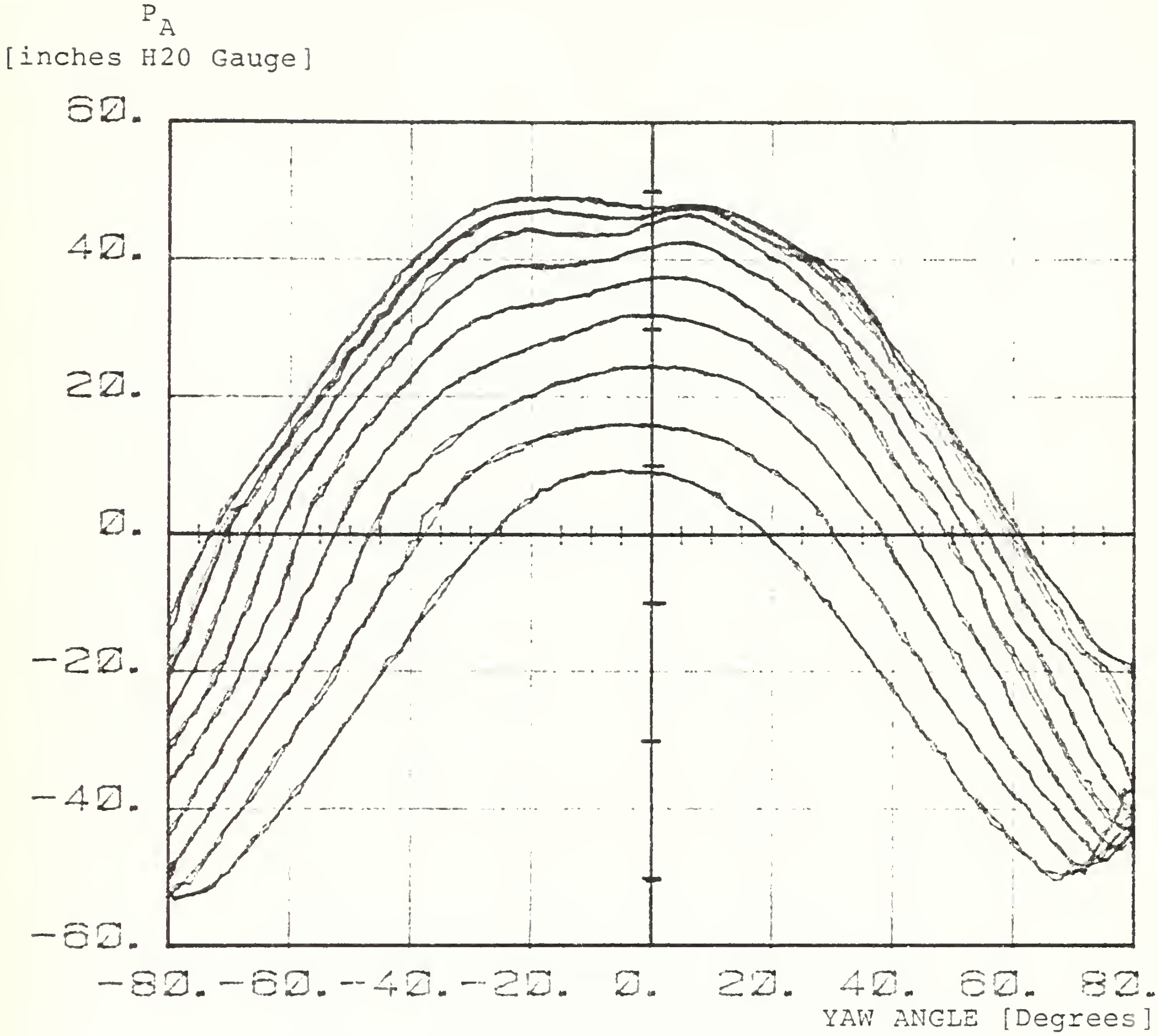


Figure 10. Type B-Probe Calibration Data at Mach = 0.4. Pitch angles in the Range from -15° (Top) to +25° in 5° Increments. Some Holes in probe tip are contaminated by dirt.

Figure 11a. Probe Tip with Dirt in Some Holes

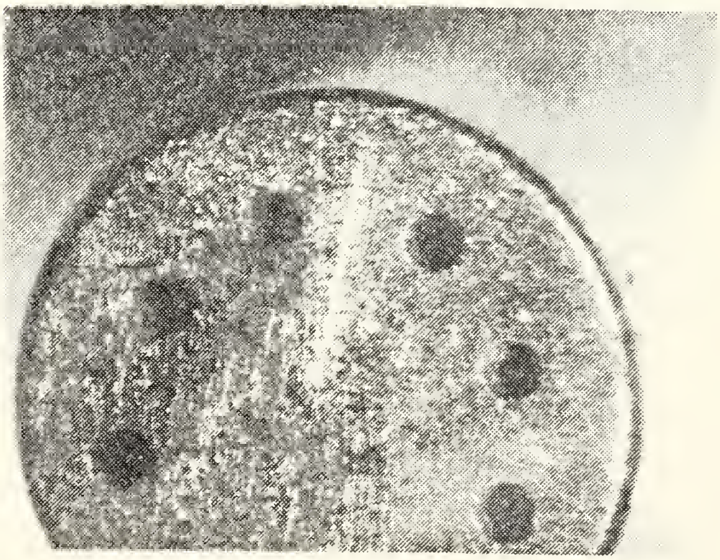


Figure 11b. Probe Tip with Dirt in Some Holes

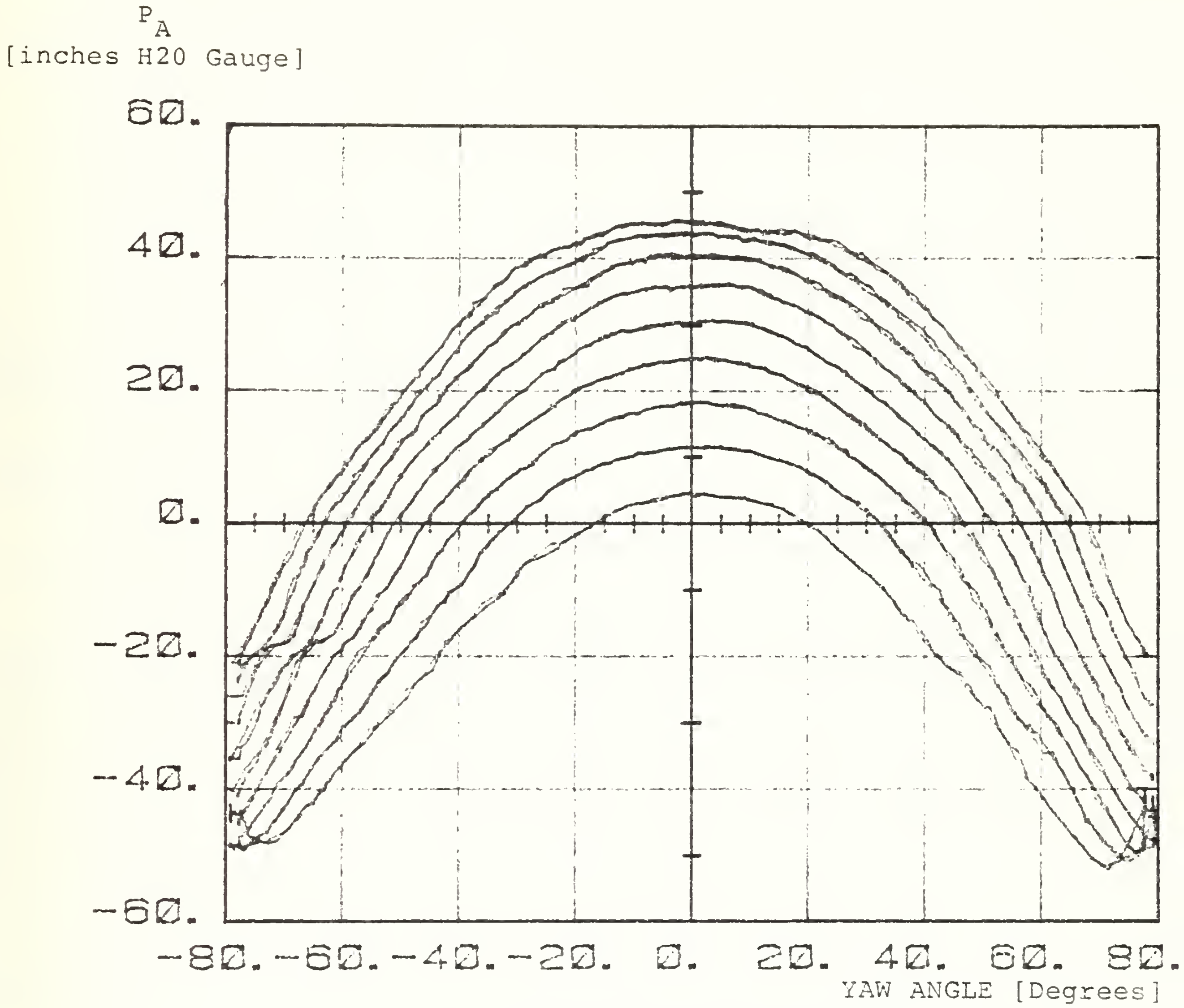


Figure 12. Type B-Probe Calibration Data at Mach = 0.4. Pitch angles in the Range from -15° (Top) to +25° in 5° Increments. Clean Probe Tip.

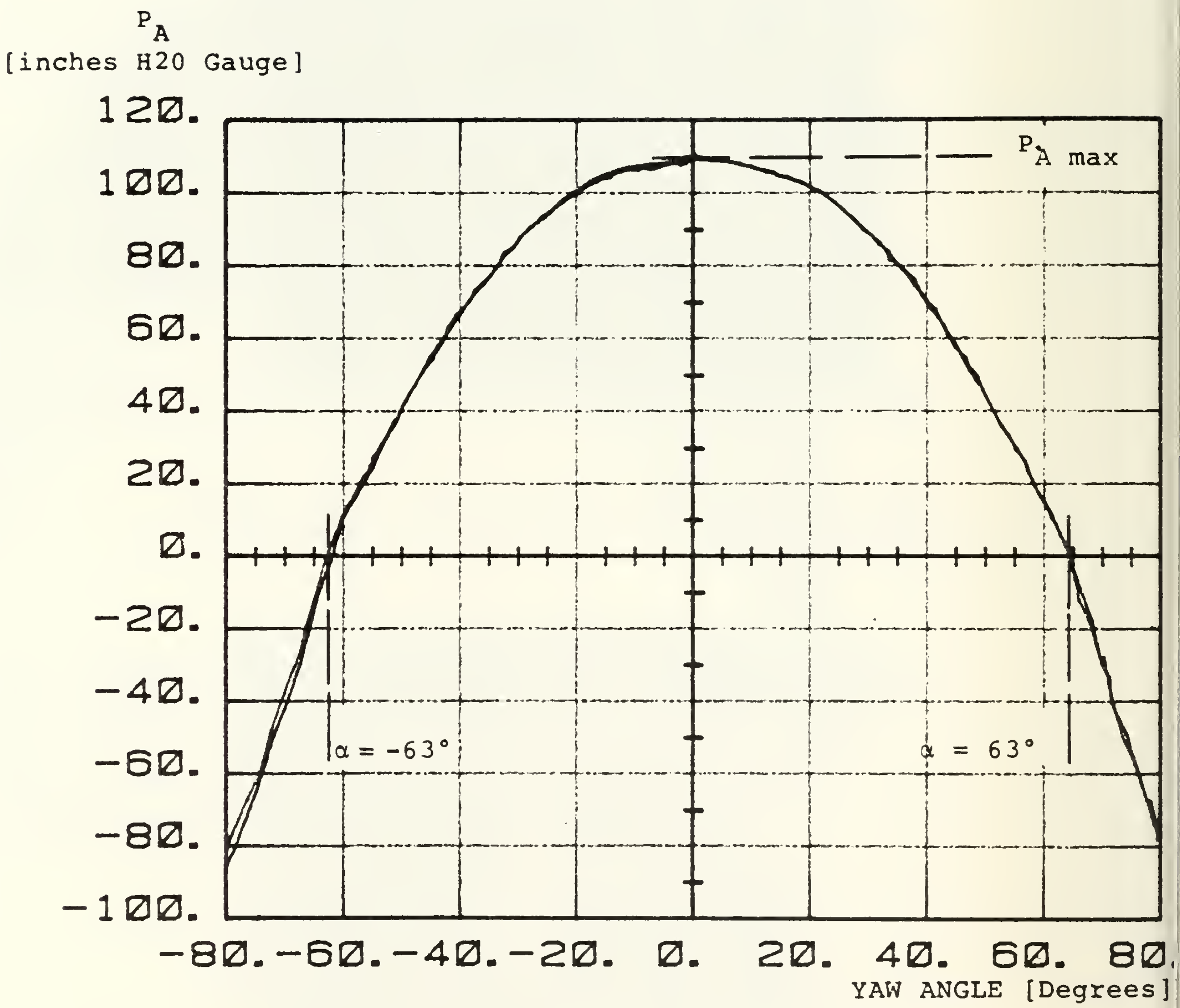


Figure 13. Type A-Probe Output Demonstrating Characteristic Values. (Mach = 0.6, Pitch angle = 25°)

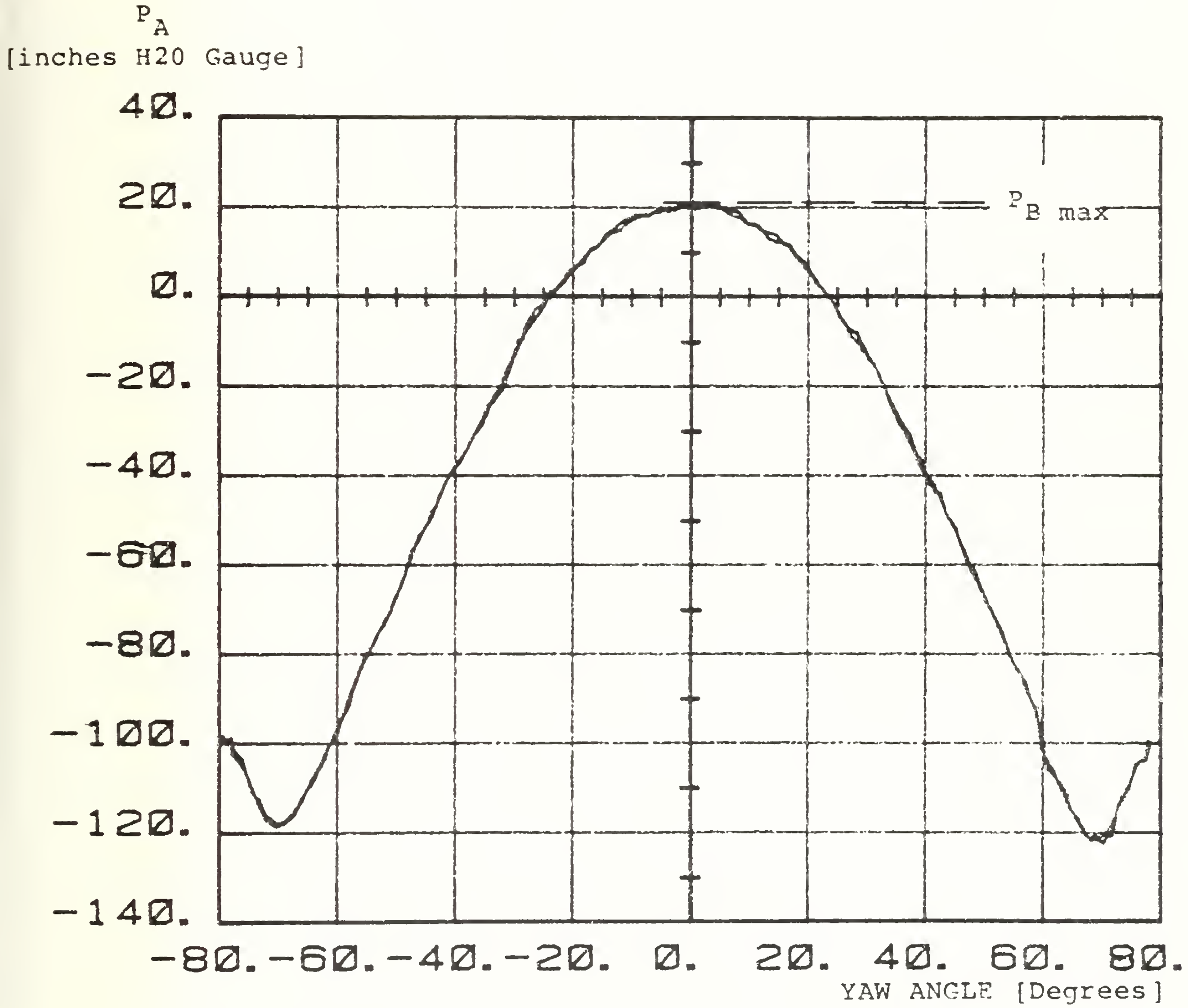


Figure 14. Type B-Probe Calibration Data
(Mach = 0.6, Pitch angle = 25°)

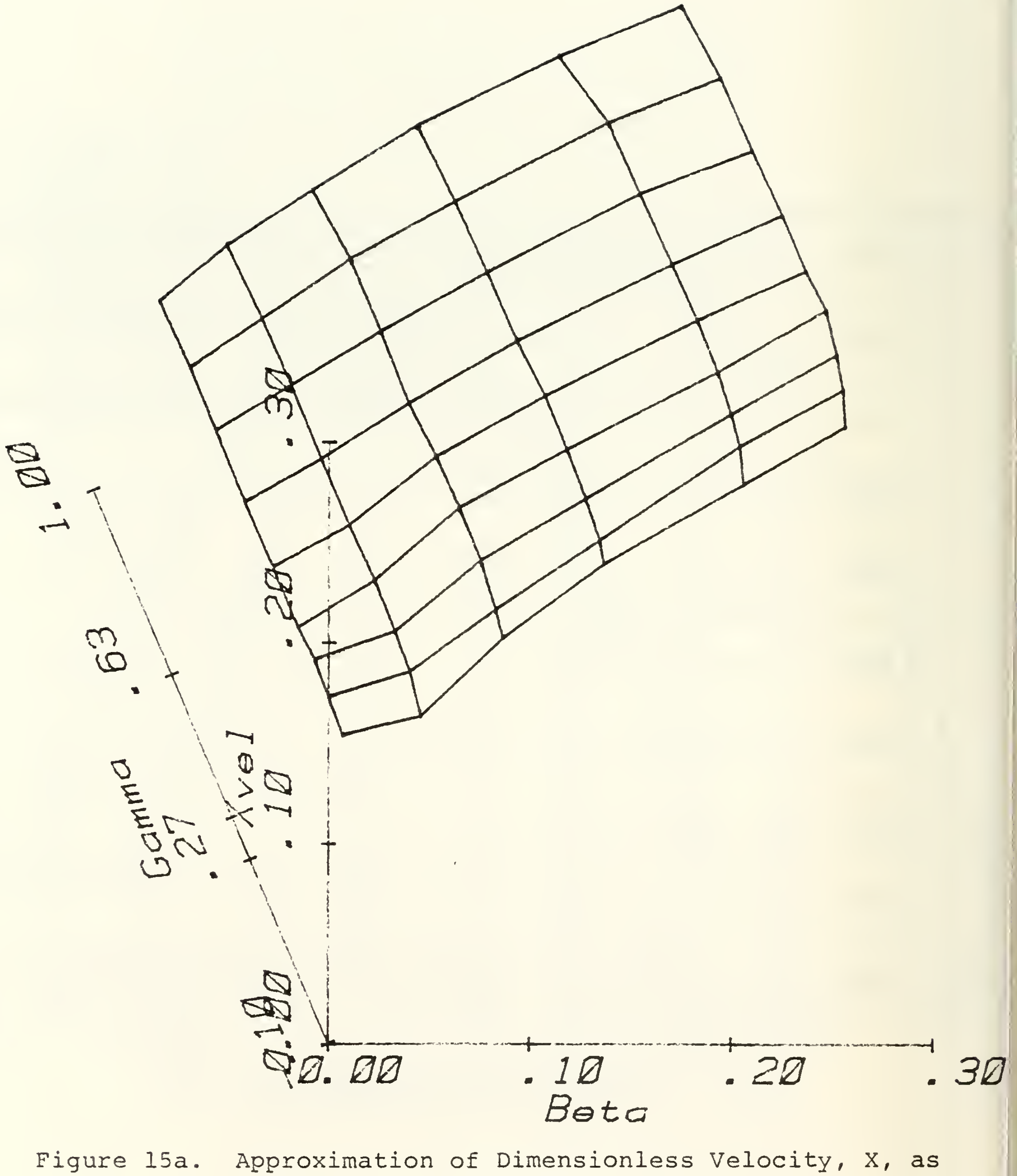


Figure 15a. Approximation of Dimensionless Velocity, X, as Function of Coefficients β and γ.

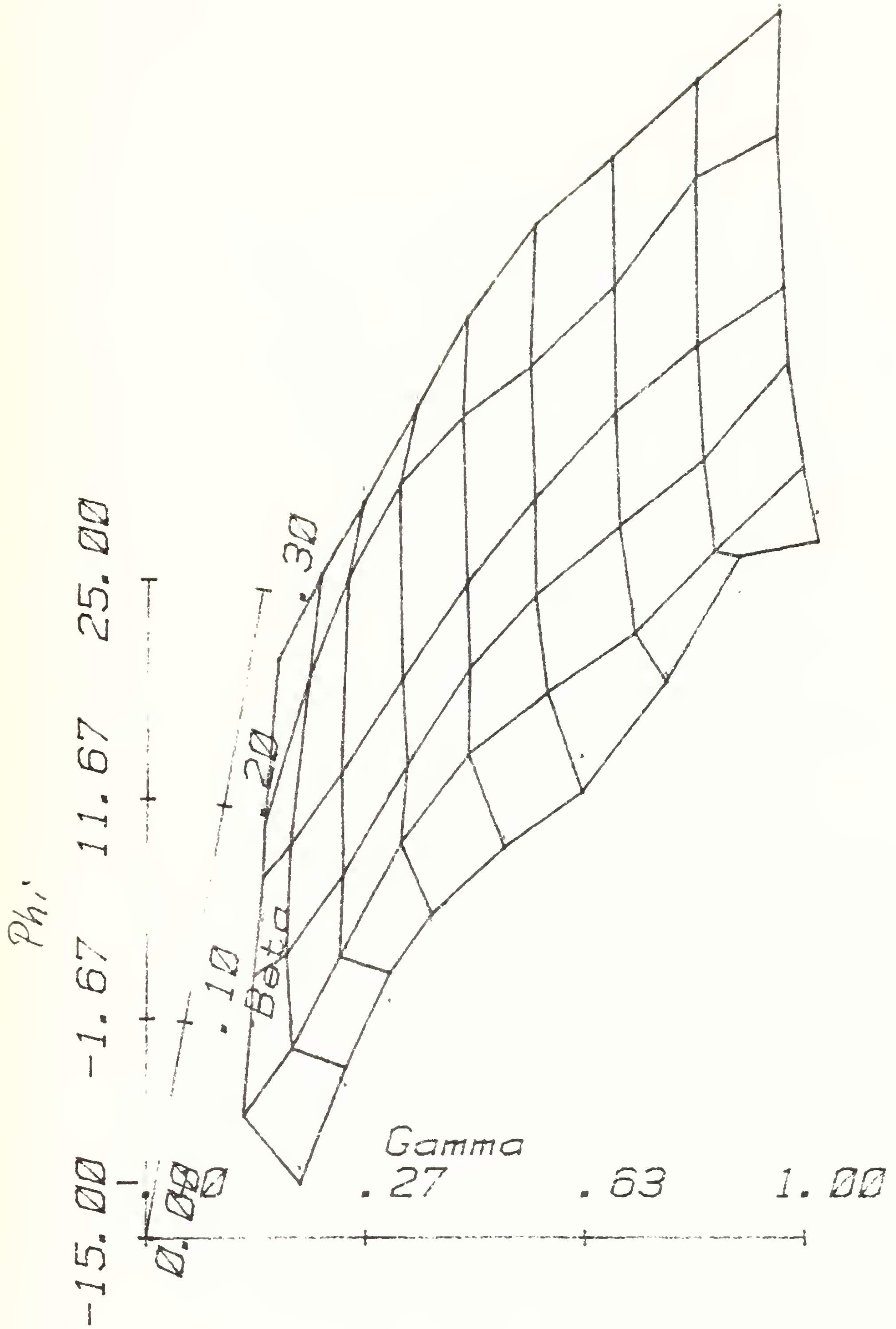


Figure 15b. Approximation of Pitch angle ϕ as Function of Coefficients β and γ.

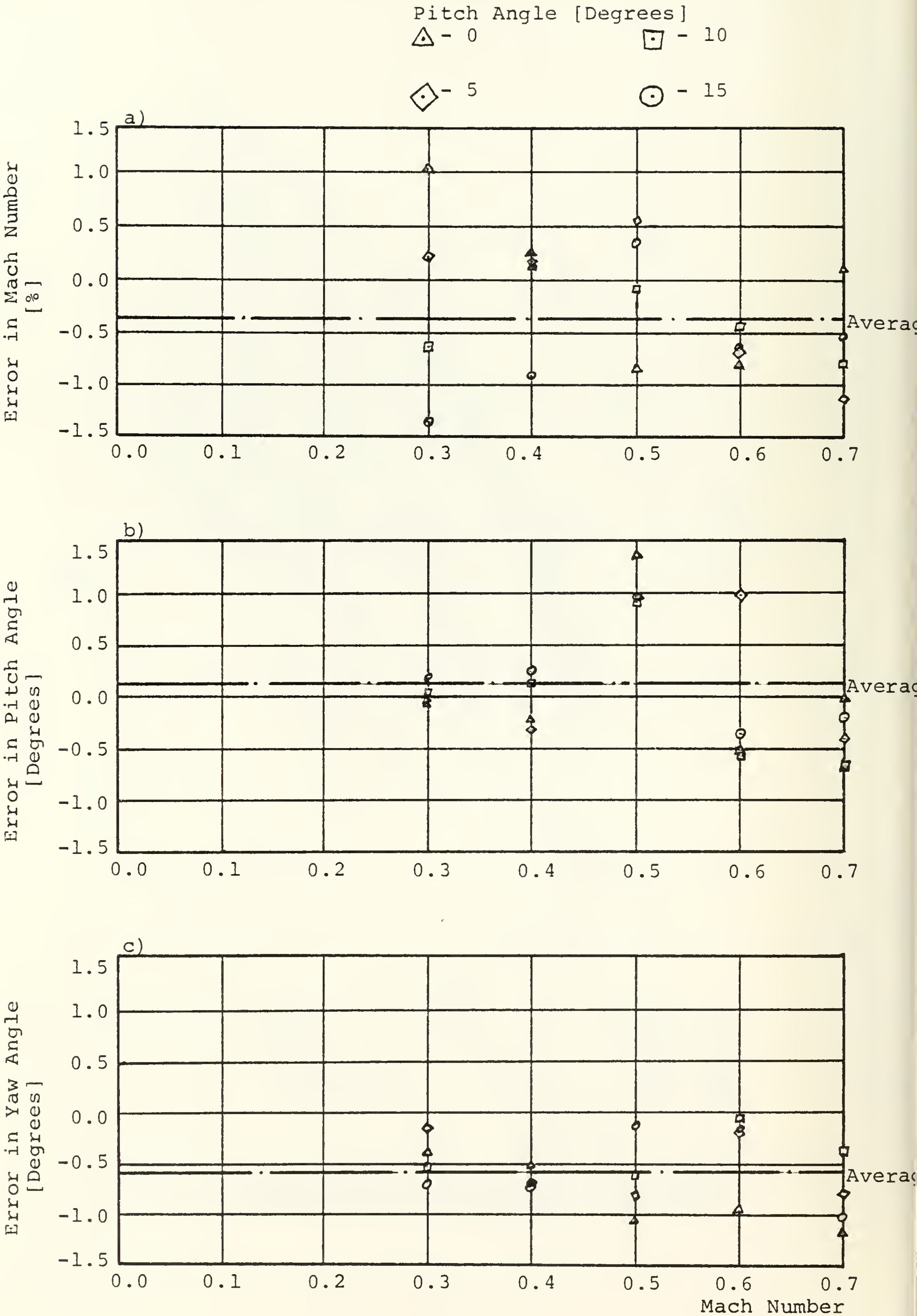


Figure 16. Errors as Specified Depending on Mach Number and Pitch Angle.

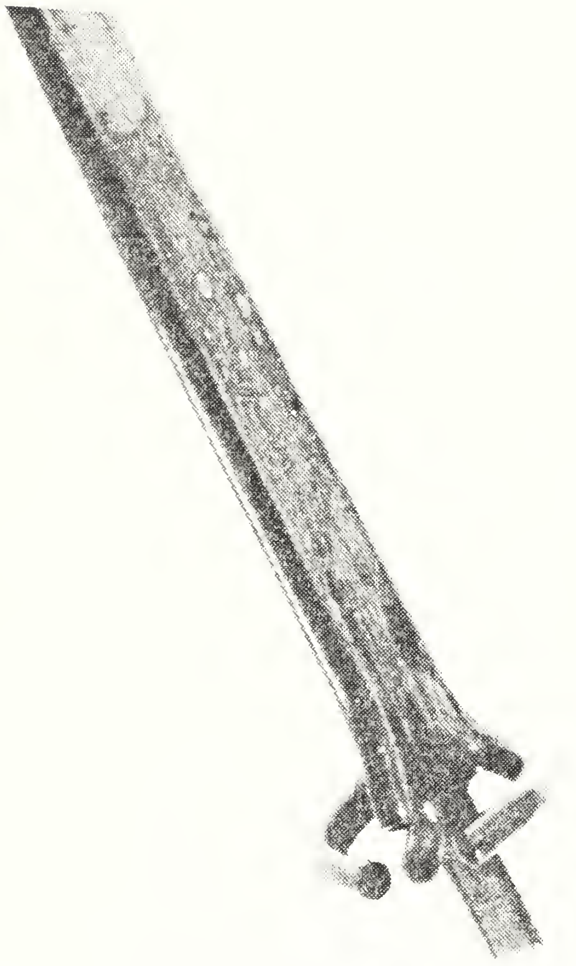


Figure 17. Combination Pressure Temperature Probe (Tip Detail)

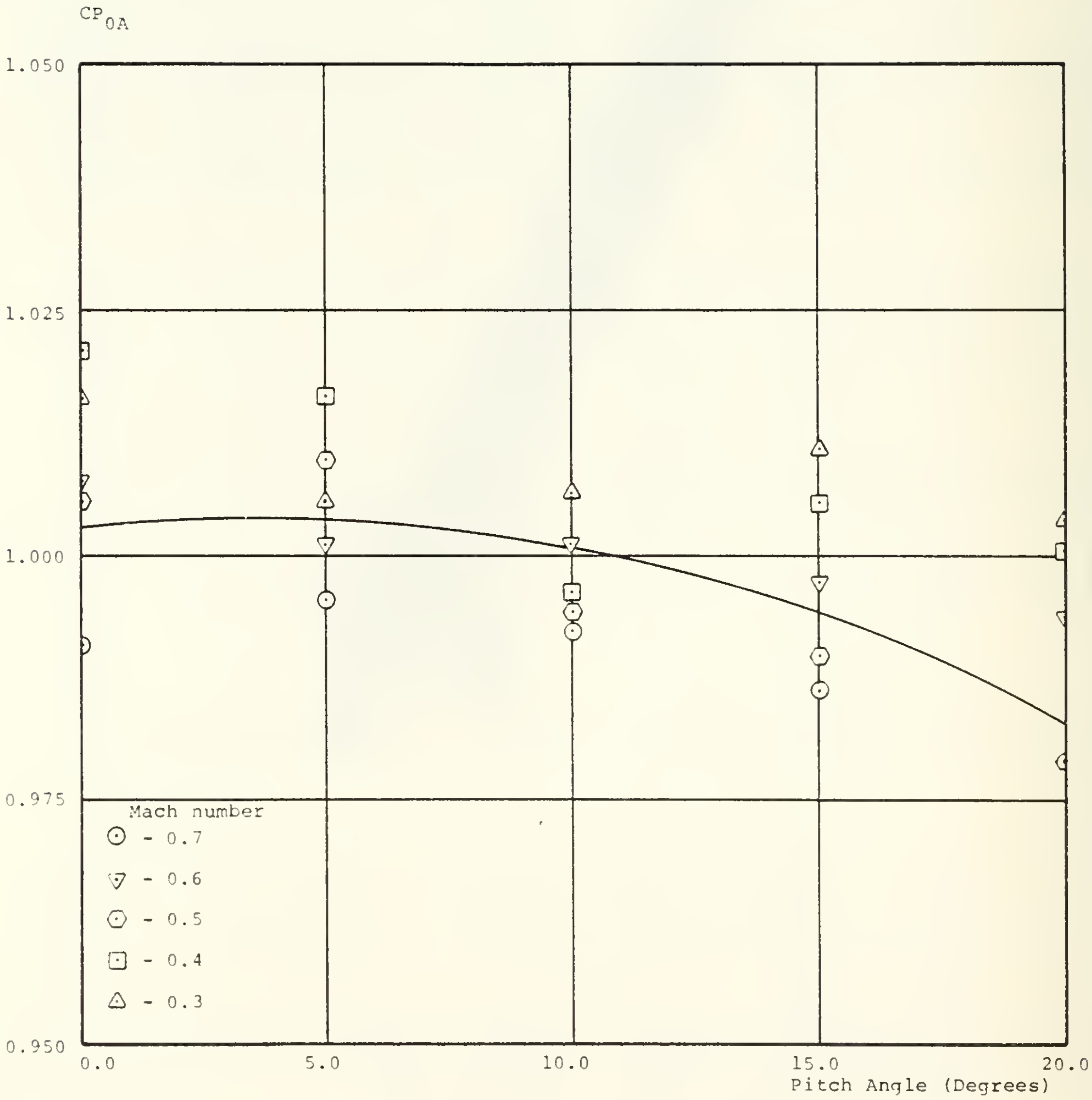


Figure 18. Pressure Coefficient for Type A-Probe at Zero Yaw Angle as Function of Mach Number and Pitch Angle.

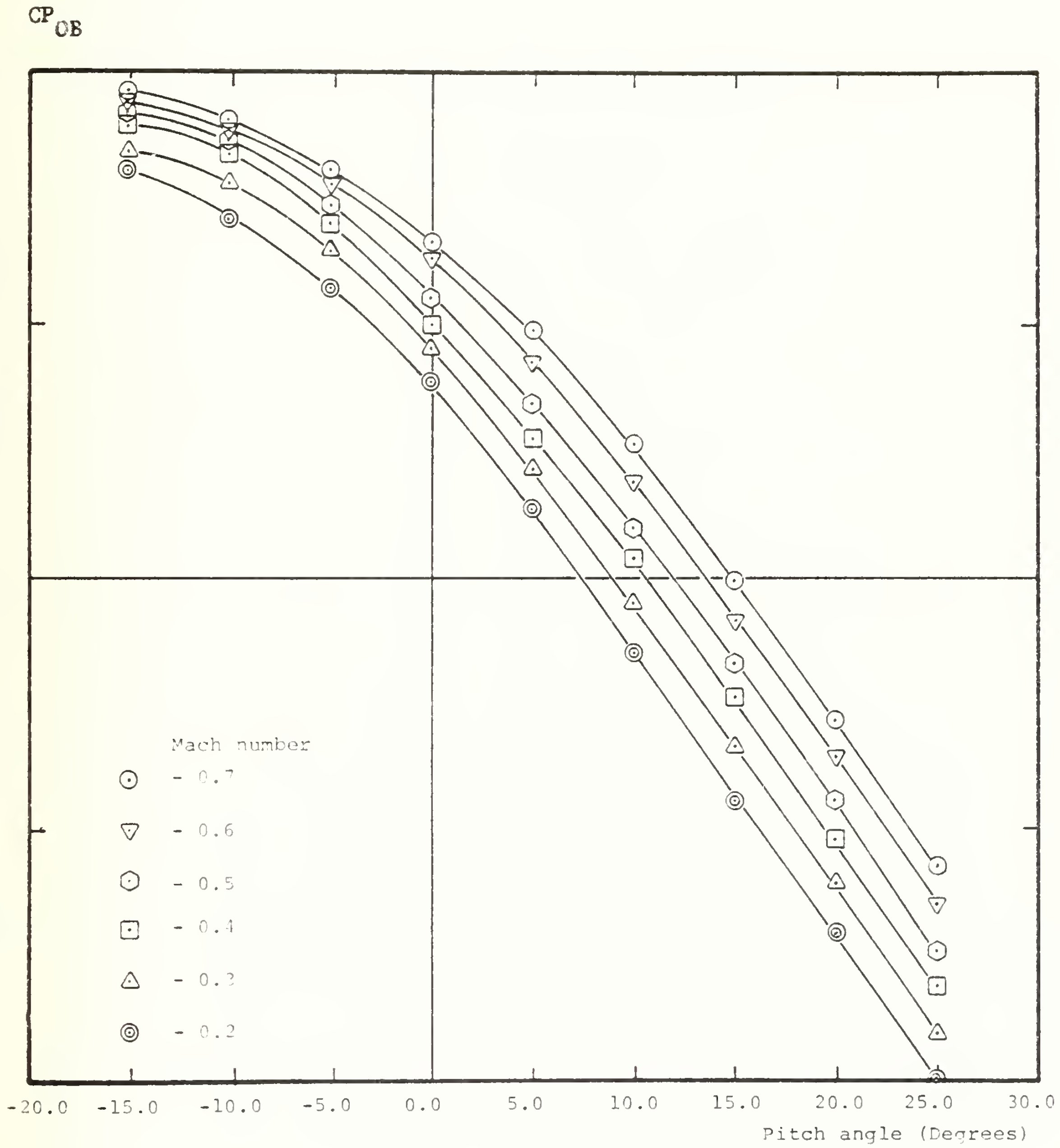
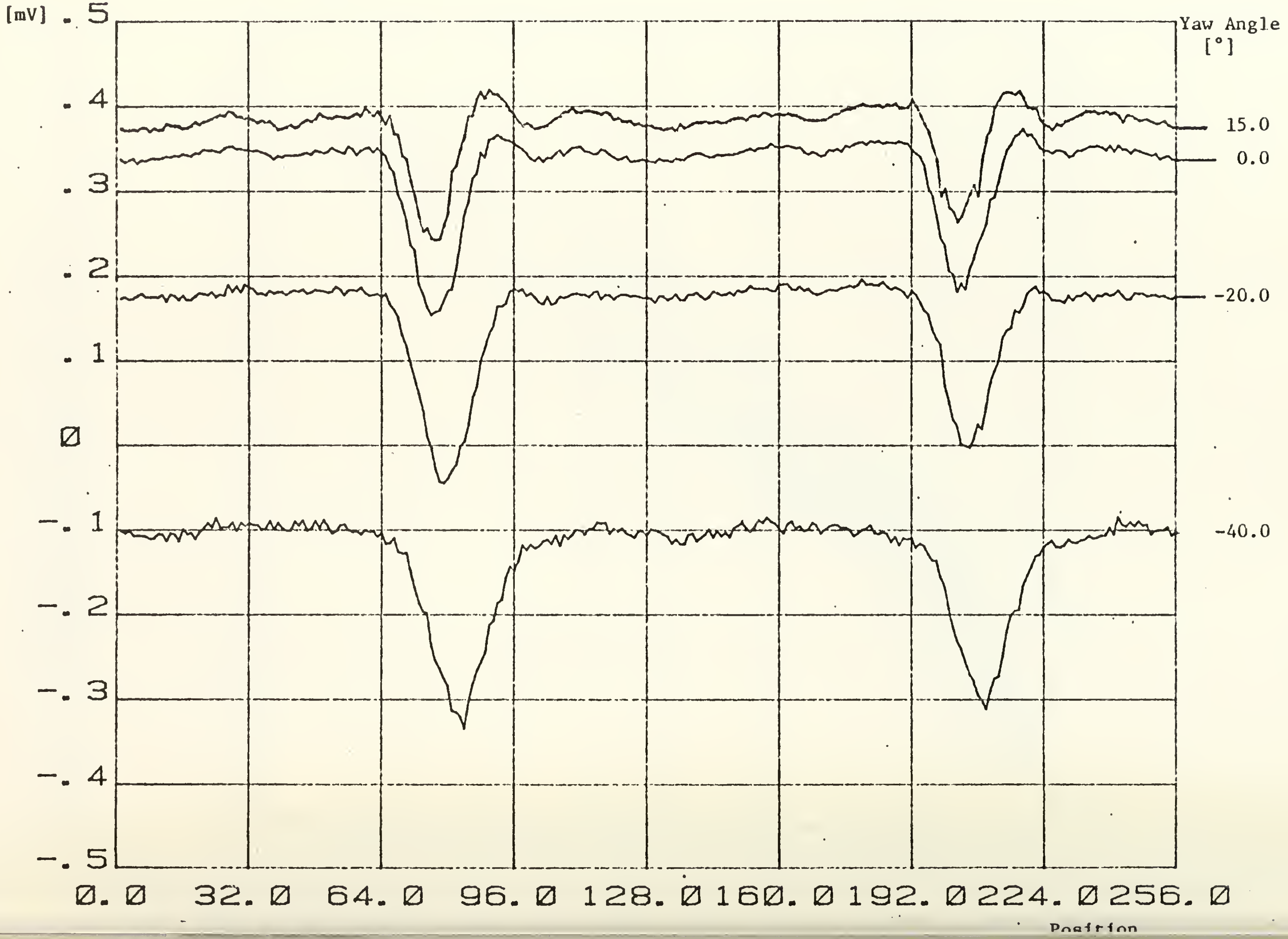


Figure 19. Pressure Coefficient for Type B-Probe for Zero Yaw Angle as Function of Mach Number and Pitch Angle.

A-probe raw data

File: AB19A1



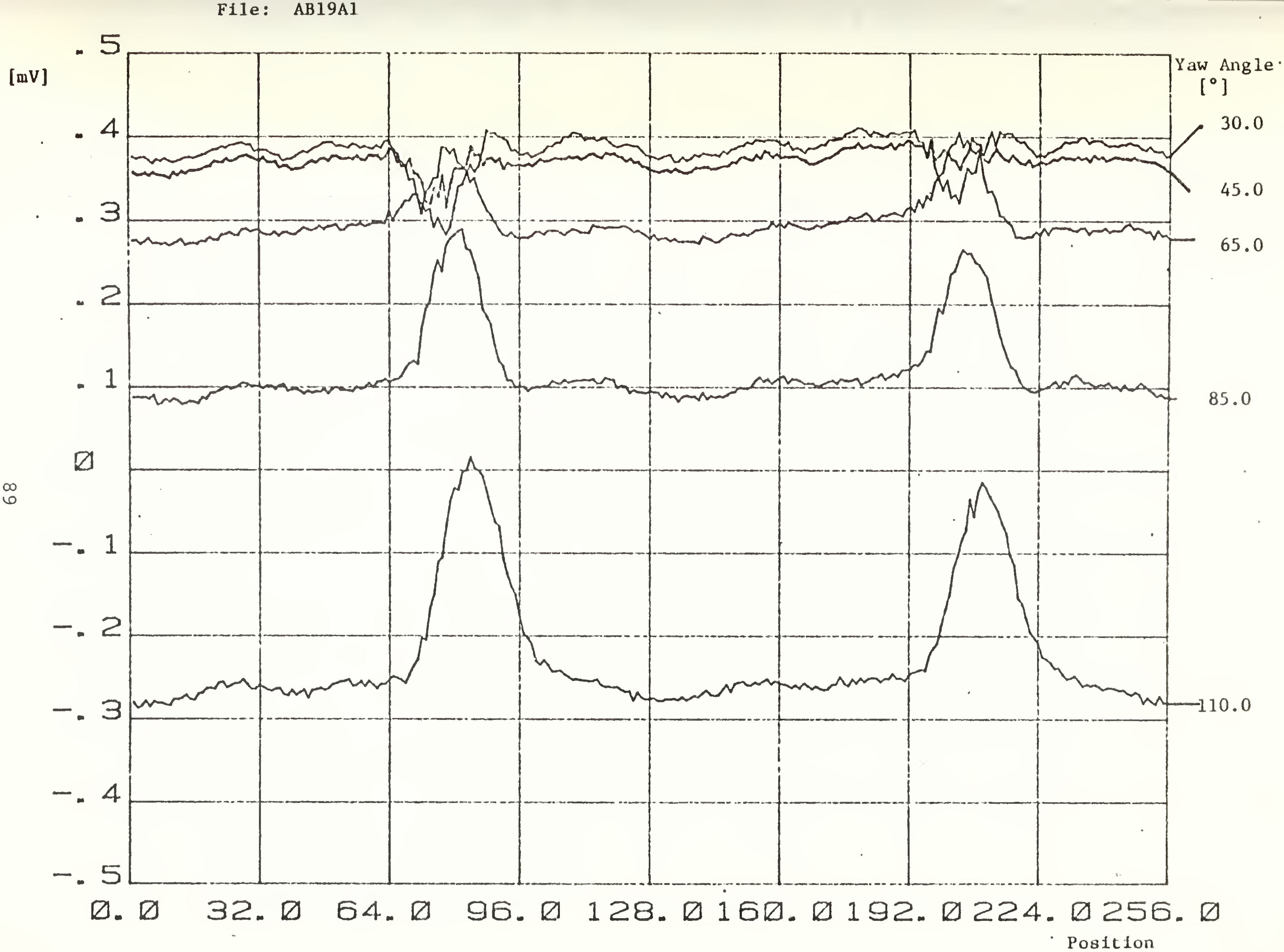


Figure 20b. Paced Data From Type A Probe. Probe Yaw Angle Settings as Indicated.

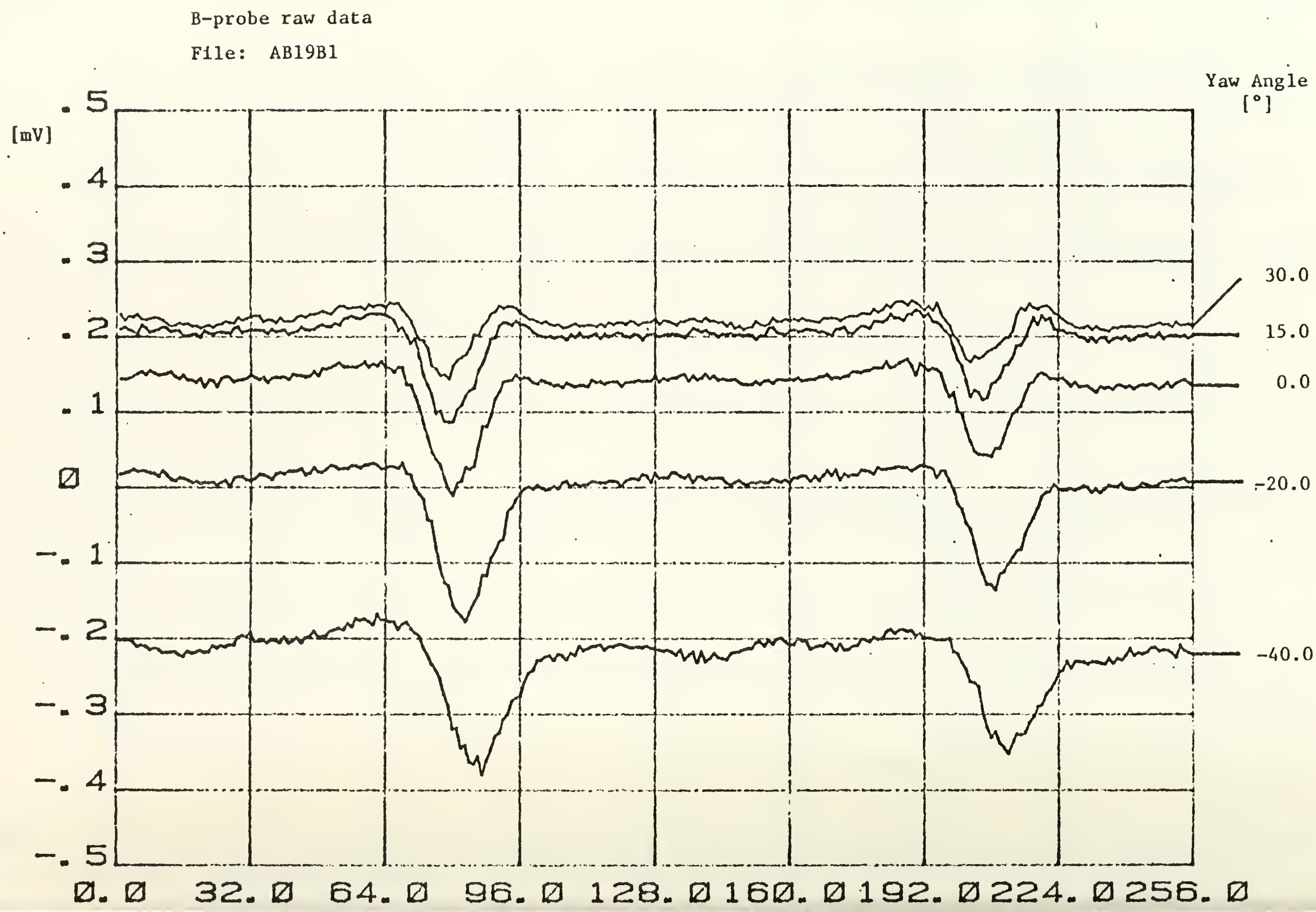


Figure 20c. Paced Data from Type B-Probe.

B-probe raw data

File: AB19B1

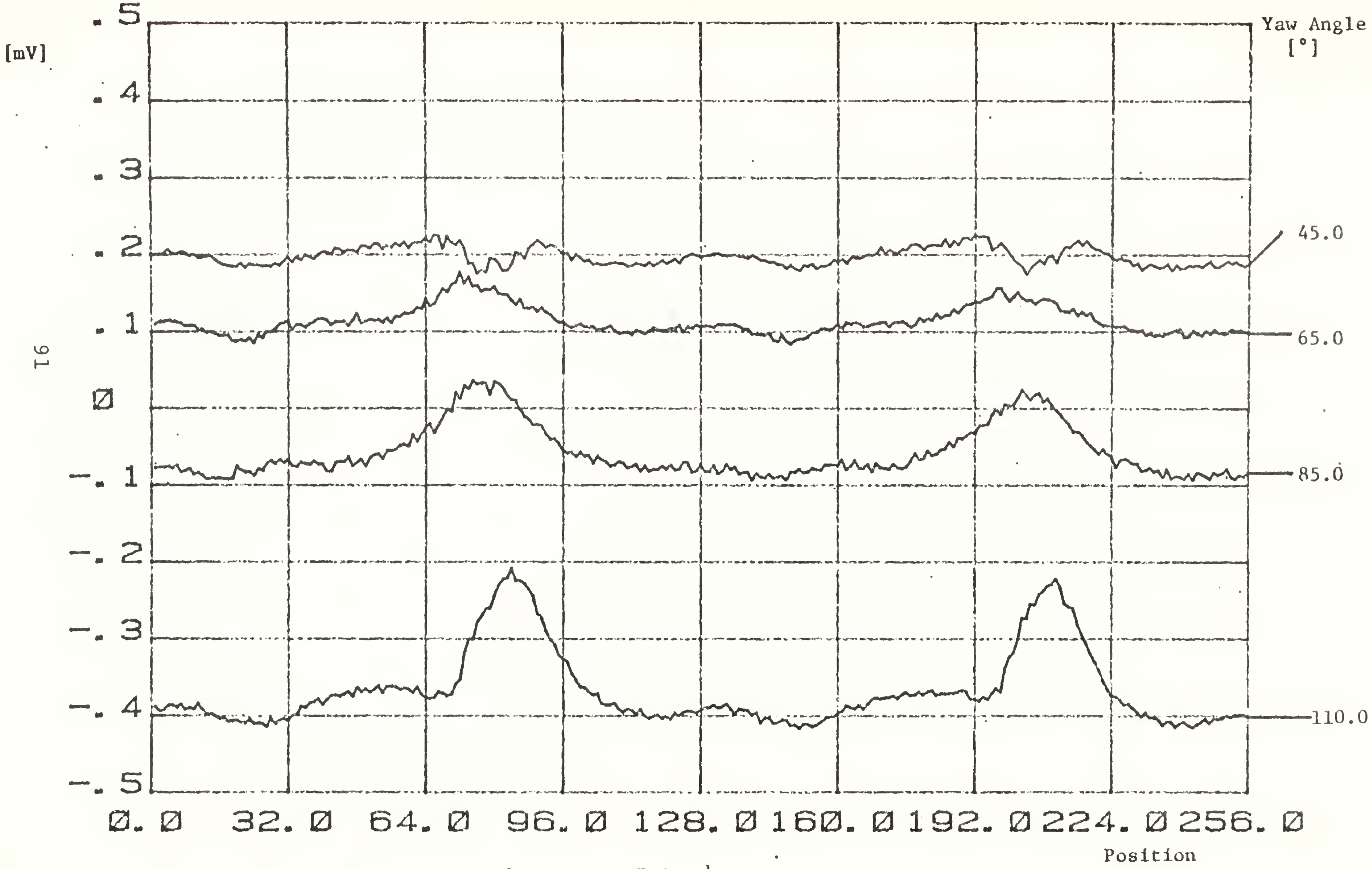


Figure 20d. Paced Data from Type B-Probe
Probe Yaw Angle Settings as Indicated.

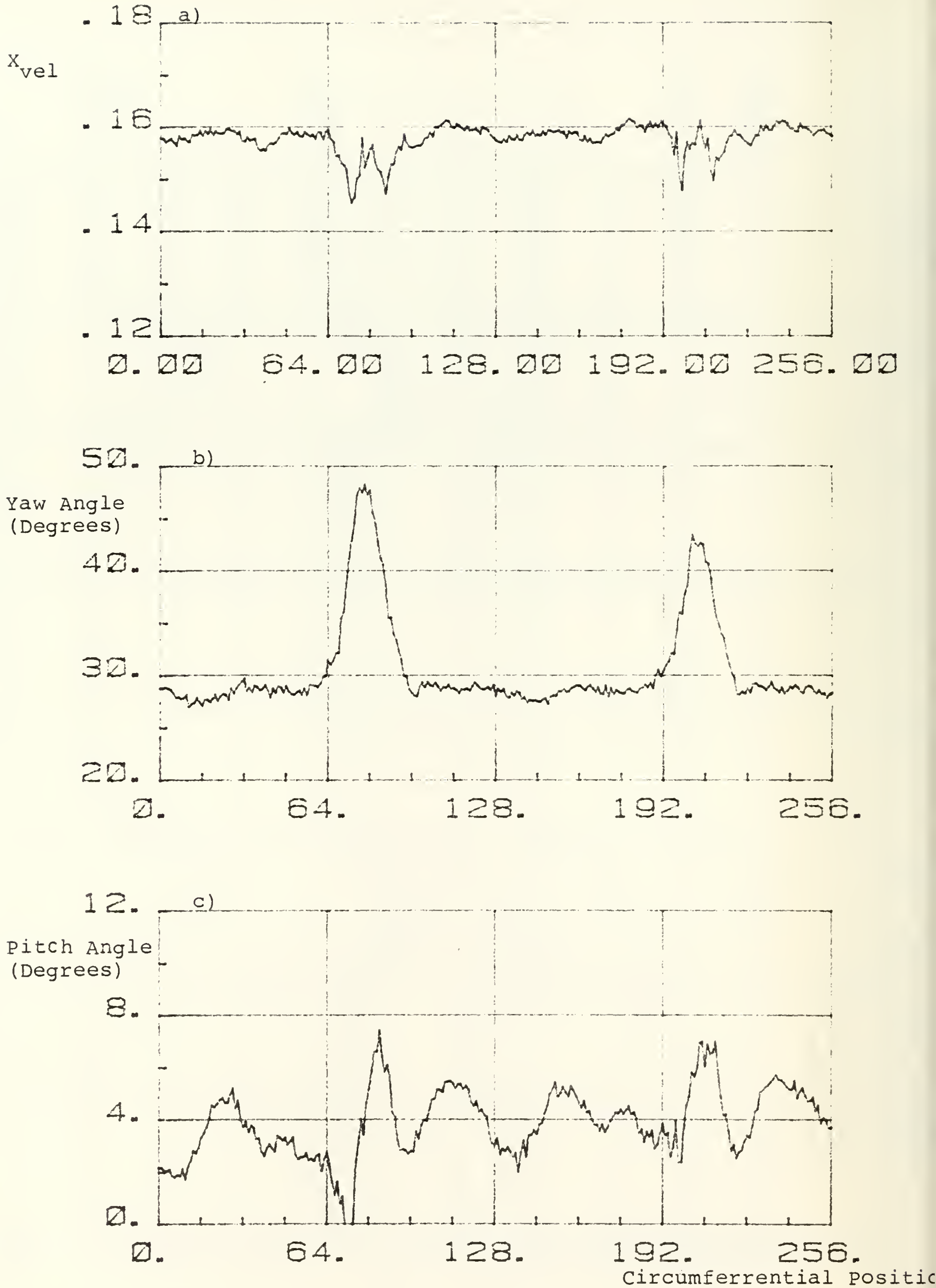


Figure 21. Measurement Results at 50% Speed, Midspan, **Peak Efficienc**
(File AB19R1).

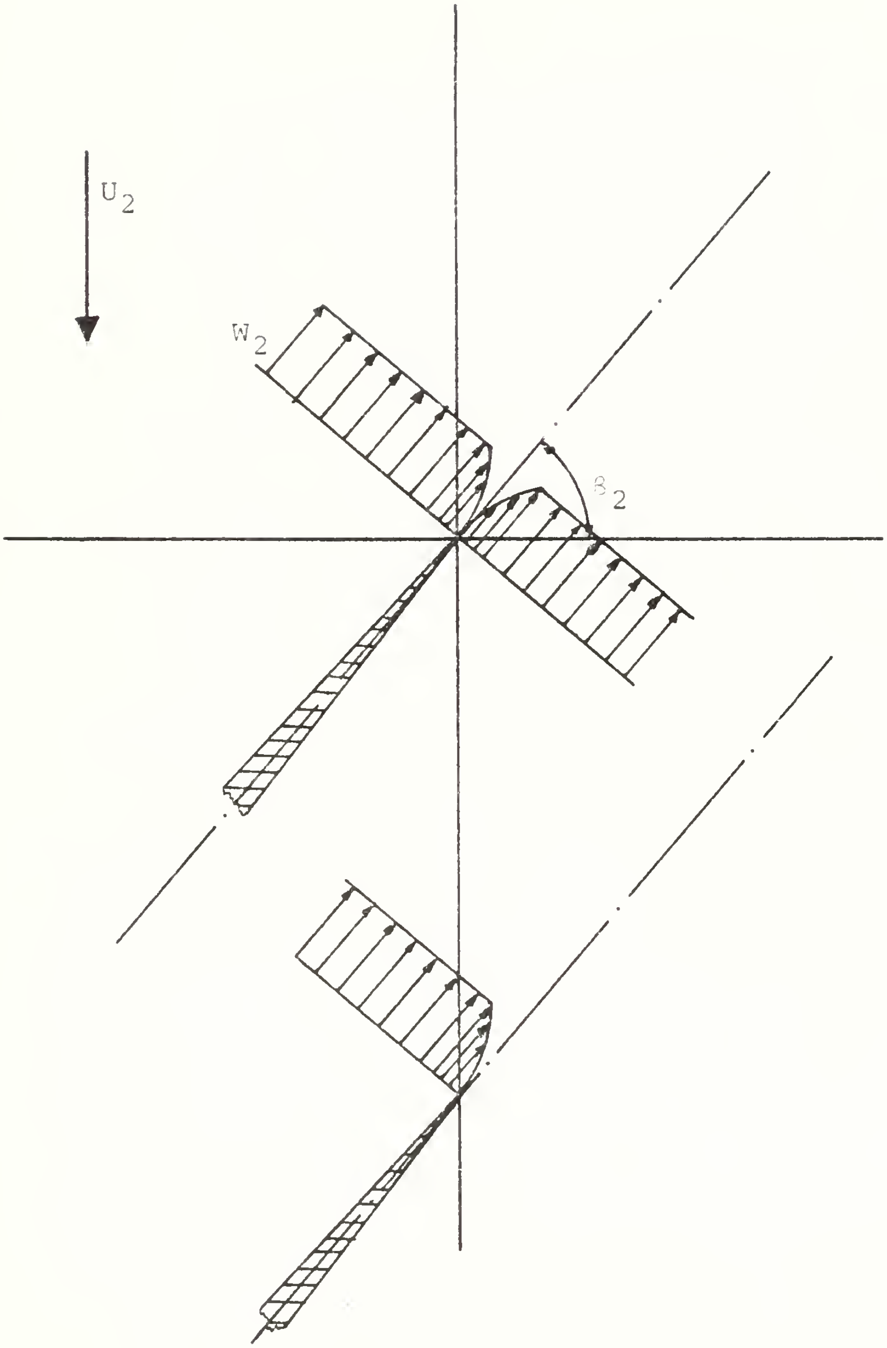
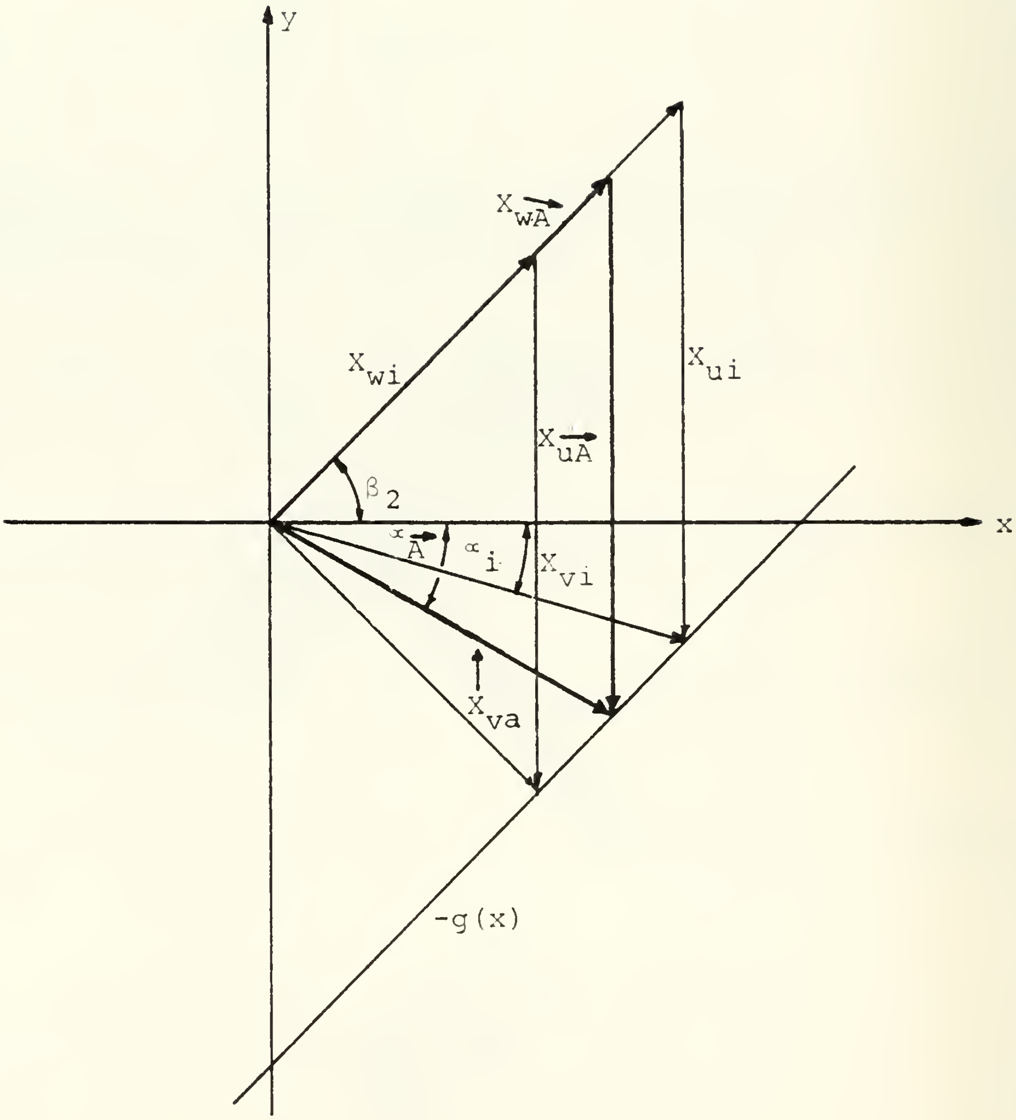


Figure 22. Relative Velocity Distribution W_2 at Rotor Trailing Edge (Schematic)

$\beta_2 = \text{const.}$

$U_2 = \text{const.}$



$$g(x_i) = Xu_A + \tan\beta_2\, x_i \qquad -Xv_i \sin\alpha_i = -Xu_i + \tan\beta_2\, Xv_i \cos\alpha_i$$

$$x_i = Xv_i \cos\alpha_i \qquad Xu_A = Xu_i = Xu$$

$$y_i = Xv_i \sin(360^\circ) - \alpha_i) \qquad Xv_i = \frac{Xu}{\tan\beta_2 \cos\alpha_i + \sin\alpha_i}$$

$$y_i = (-Xv_i)\sin\alpha_i$$

Figure 23. Velocity Triangles for Varying Values of the Relative Velocity X_W.

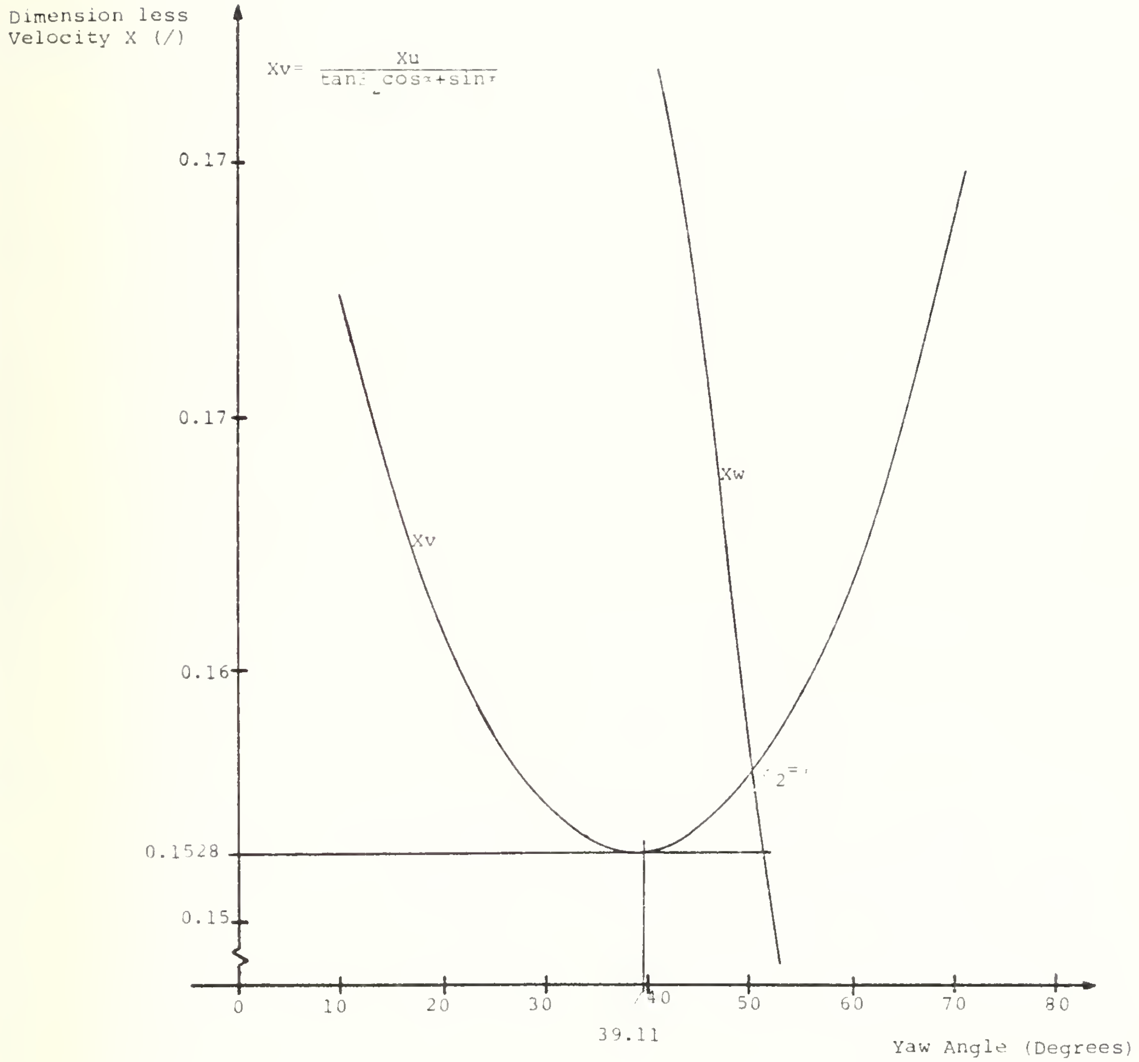


Figure 24. Dependence of Absolute (Xv) and Relative (Xw) Velocities on Yaw Angle (α) Assuming Constant Values of Circumferrential Velocity (Xu=0.24219) and Relative Flow-Angle (β_2=50.89°).

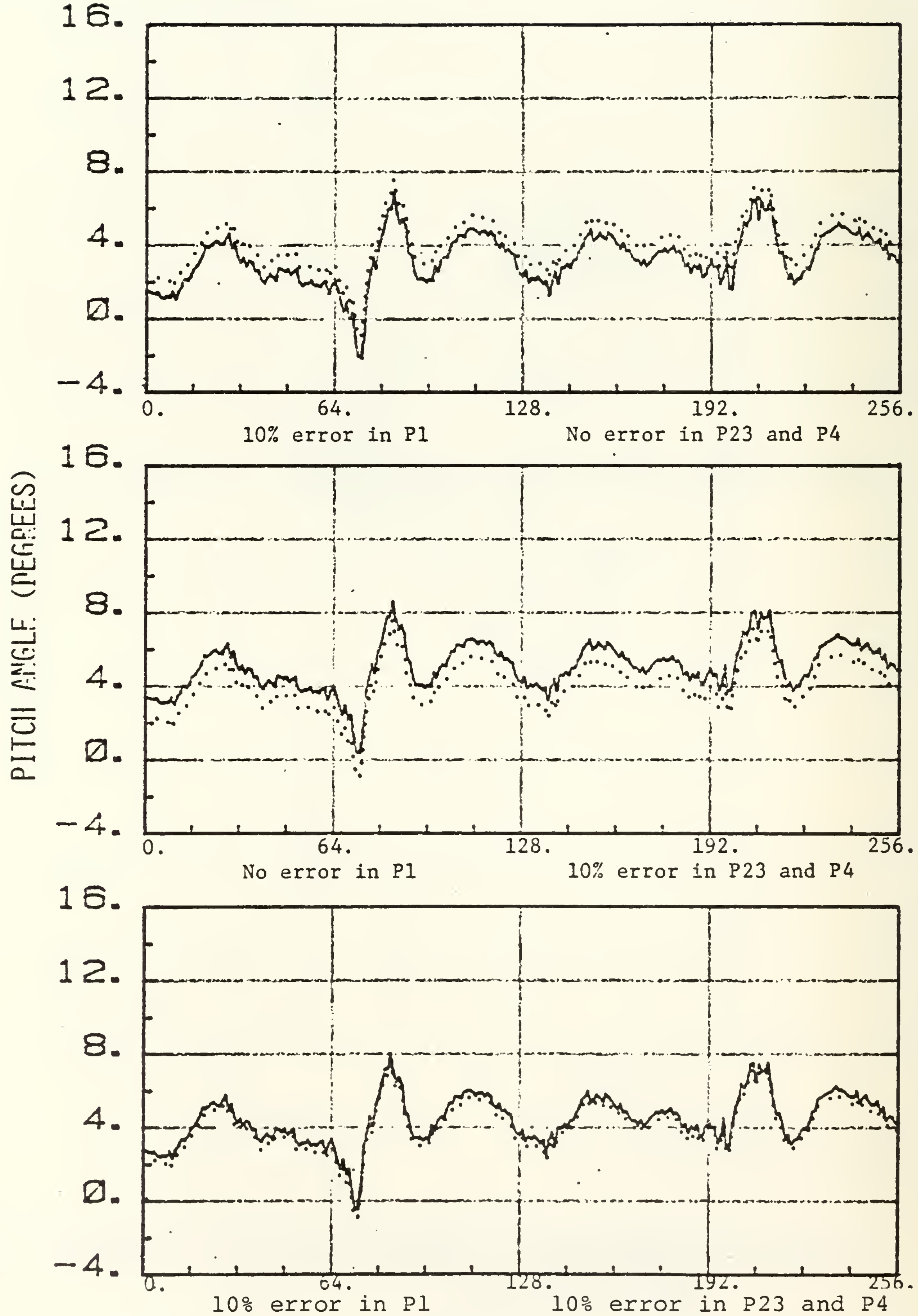


Figure 25. Influence of Incorrect Pneumatic Probe Pressure Readings Run 11 50% Design Speed, Near Peak Efficiency, Dotted Line - No Errors

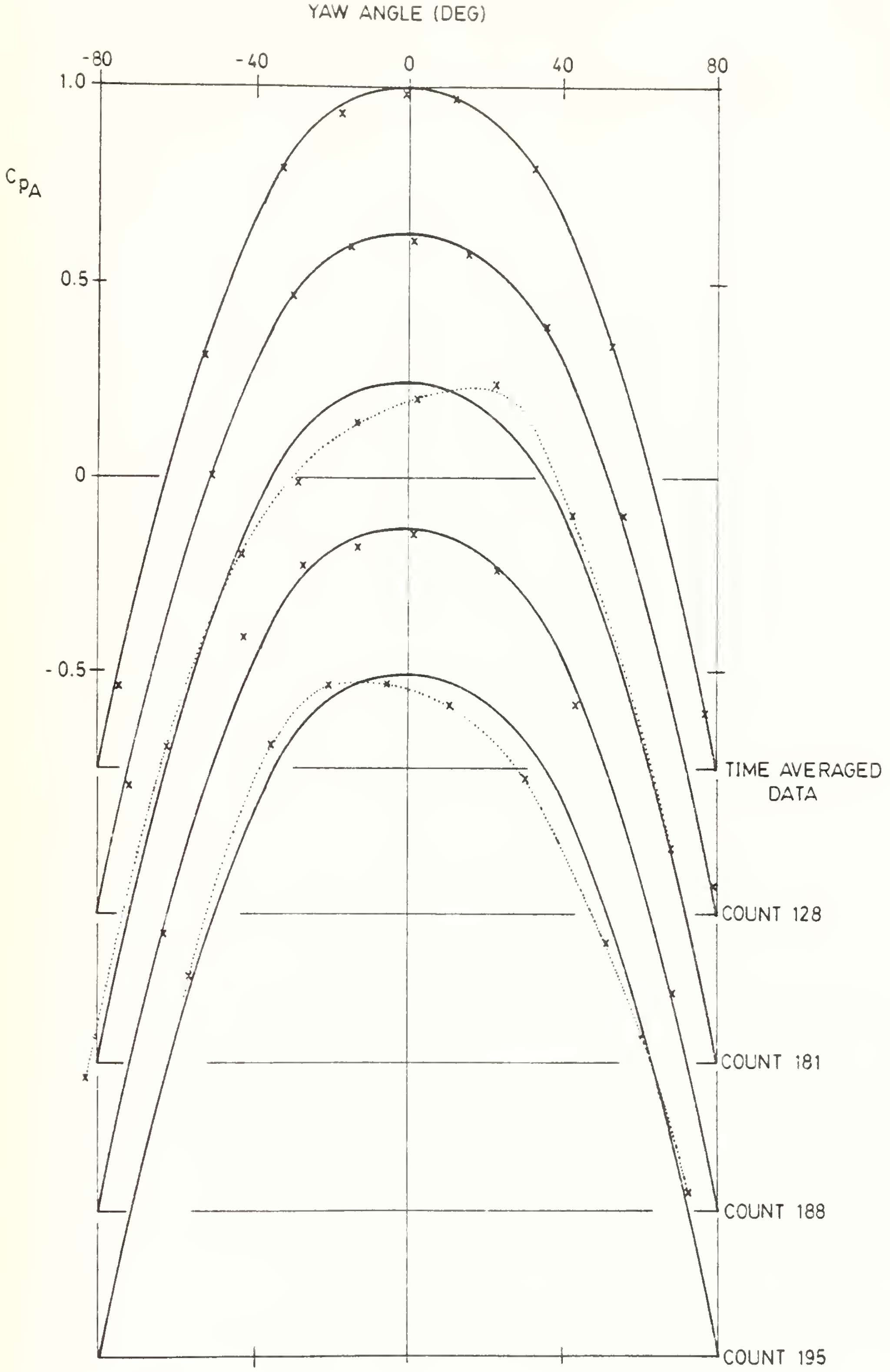


Figure 26. Pressure Coefficient Versus Yaw Angle for Type A Probe at Specific Positions in Rotor Flow Field (Run 123 - solid line is from calibration at M = 0.4 , ϕ = 0°).

APPENDIX A

CHANGES MADE TO SOFTWARE FROM (Ref. 4)

The changes made by McCarville and reported in Ref. 4 brought about two general improvements: hardware changes which eliminated the need for an operator-performed lock-on procedure and software changes which allowed the acquisition of one sample for each consecutive revolution instead of every tenth or eleventh as before. In the process of integrating the new software into the data acquisition program, one minor and one significant error was found in the subroutines used for acquiring data through the A/D converter.

The data is transferred from the A/D converter to the 21MX computer in 16-bit words. Only the highest 10 bits contain the digitized voltage while the A/D channel number (0 through 15) is transferred in the lowest 4 bits. Using the highest bit for the sign, the range of numbers which can be transferred is thus $\pm(2^{15}-1)$ or $\pm 32,767$, while the smallest meaningful division is 2^6 or 64. The resolution which can be achieved therefore is $\frac{2^6}{2^{16}}$ or 2^{-10} or 0.000976 of full range. Since the full range of the A/D is -1V to +1V, the instrument resolution is to about 2 mV.

The procedure of masking can be used to derive an exact digital number solely from the highest 10 bits of the transmitted word. If this is not done, the A/D channel number from the low bits is included when converting the data word to a decimal number. The result is to create decimal numbers which <u>appear</u>

to be changing with a resolution of 2° is ±32,767 or 0.0305 mvs. Since the increase in program running time due to masking was insignificant, this procedure was built into the data acquisition program.

The second error was found while using the data acquisition program. It was noted that a different number of samples acquired from the same machine conditions did not bring any significant change in the smoothness of the output. An examination of the output of 5 individual samples (Table A-I) and the average derived from these samples showed that only the first sample was converted from an integer into a real number and that the same real number resulted for each individual sample no matter what was the value of the integer.

Figure A-1 shows the listing of the original subroutine (RPACE) from McCarville which acquires raw data. The single samples are read into array IBUFF(99) correctly (lines #90 and #125). The conversion into real numbers is incorrect, in that only the first value of the array IBUFF(99) is converted.

Figure A-2 shows the corrected DO-loop.

Table A-II shows values achieved using the corrected subroutine. It can be seen that changes in the integer numbers are reflected in the calculated real numbers.

In the acquisition program discussed herein a subroutine similar to the one of Fig. A-2 was used.

```
REP # = 1IBUF = -115[illegible] ROFF = -.[illegible]
REP # = 2IBUF = -16125 ROFF = -[illegible]
REP # = 3IBUF = -19840 ROFF = -.35[illegible]
REP # = 4IBUF = -22400 ROFF = -[illegible]
REP # = 5IBUF = -23[illegible] ROFF = -.[illegible]
POINT # = 1Y(I) = -.0[illegible]
REP # = 1IBUF = -1[illegible] ROFF = -.515625
REP # = 2IBUF = -2041[illegible] ROFF = -.515625
REP # = 3IBUF = -22592 ROFF = -.515625
REP # = 4IBUF = -23[illegible] ROFF = -.515625
REP # = 5IBUF = -23424 ROFF = -.515625
POINT # = 2Y(I) = -.1[illegible]5
REP # = 1IBUF = 2516[illegible] ROFF = .[illegible]
REP # = 2IBUF = 2[illegible] ROFF = .[illegible]
REP # = 3IBUF = [illegible] ROFF = .[illegible]
REP # = 4IBUF = 1[illegible] ROFF = .[illegible]
REP # = 5IBUF = 14[illegible] ROFF = .[illegible]
POINT # = 3Y(I) = .1[illegible]5
REP # = 1IBUF = 220[illegible]0 ROFF = .[illegible]
REP # = 2IBUF = 19[illegible] ROFF = .[illegible]
REP # = 3IBUF = 1[illegible] ROFF = .[illegible]
REP # = 4IBUF = 11[illegible] ROFF = .[illegible]
REP # = 5IBUF = [illegible] ROFF = .[illegible]
POINT # = 4Y(I) = .1[illegible]5
REP # = 1IBUF = -13[illegible] ROFF = -.562500
REP # = 2IBUF = -145[illegible] ROFF = -.562500
REP # = 3IBUF = -9[illegible] ROFF = -.562500
REP # = 4IBUF = -4096 ROFF = -.562500
REP # = 5IBUF = -1472 ROFF = -.562500
POINT # = 5Y(I) = -.1125[illegible]
```

Table A-I. Results Using Uncorrected Subroutine RPACE (& A2D, McCarville, Ref. 4)

```
REP # =   1IBUF =    -28736 RBUFF =     -.876953
REP # =   2IBUF =    -28608 RBUFF =     -.873047
REP # =   3IBUF =    -28736 RBUFF =     -.876953
REP # =   4IBUF =    -28608 RBUFF =     -.873047
REP # =   5IBUF =    -28608 RBUFF =     -.873047
POINT # =  1Y(I) =    -.874609
REP # =   1IBUF =    -28480 RBUFF =     -.869141
REP # =   2IBUF =    -28416 RBUFF =     -.867188
REP # =   3IBUF =    -28480 RBUFF =     -.869141
REP # =   4IBUF =    -28352 RBUFF =     -.865234
REP # =   5IBUF =    -28416 RBUFF =     -.867188
POINT # =  2Y(I) =    -.867578
REP # =   1IBUF =    -28160 RBUFF =     -.859375
REP # =   2IBUF =    -28096 RBUFF =     -.857422
REP # =   3IBUF =    -28160 RBUFF =     -.859375
REP # =   4IBUF =    -28096 RBUFF =     -.857422
REP # =   5IBUF =    -28224 RBUFF =     -.861328
POINT # =  3Y(I) =    -.858984
REP # =   1IBUF =    -27904 RBUFF =     -.851563
REP # =   2IBUF =    -27712 RBUFF =     -.845703
REP # =   3IBUF =    -27840 RBUFF =     -.849609
REP # =   4IBUF =    -27776 RBUFF =     -.847656
REP # =   5IBUF =    -27776 RBUFF =     -.847656
POINT # =  4Y(I) =    -.848438
REP # =   1IBUF =    -27264 RBUFF =     -.832031
REP # =   2IBUF =    -27392 RBUFF =     -.835938
REP # =   3IBUF =    -27456 RBUFF =     -.837891
REP # =   4IBUF =    -27392 RBUFF =     -.835938
REP # =   5IBUF =    -27520 RBUFF =     -.839844
POINT # =  5Y(I) =    -.836328
```

Table A-II. Results Using Corrected Subroutine RPACE (&A2D, McCarville, Ref. 4)

```
      SUBROUTINE RPACE (ICHAN,IAVG,ISURV,IMODE,IPAIR,
     CIPOSIT,IOFFS,N2)
C     ...........................................................
C     .
C     .       DATA ACQISITION SUBROUTINE
C     .
C     ...........................................................
      REAL SRVPT(256)
      DIMENSION IBUFF(99),ITIME(5)
      N=IAVG
      CALL EXEC (11,ITIME,IYEAR)
      WRITE (6,90) N2,ITIME(5),IYEAR
   90 FORMAT(//,10X,"  THIS IS TEST #",I2," RUN ON DAY ",
     *" DATE ",I3,3X,I4,//)
      IF (ISURV .EQ. 1) GO TO 120
C     ...........................................................
C     .
C     .                  SINGLE POINT ACQUISITION                 .
C     .                                                            .
C     ...........................................................
      IBLADE=256*(IPAIR-1)+IPOSIT
      IF (IMODE .EQ. 0) GO TO 100
      IBLADE=IBLADE+100000B
  100 CALL EXEC (3,19)
      CALL EXEC (1,17,IRPM,1,IBLADE)
      CALL EXEC (1,20,IBUFF,N,ICHAN,1)
      DO 110 I=1,IAVG
  110 RBUFF=RBUFF+FLOAT(IBUFF(I))/32752.
      PTDATA=RBUFF/IAVG
      GO TO 195
C     ...........................................................
C     .
C     .        SURVEY ACROSS BLADE PAIR ACQUISTION                .
C     .
C     ...........................................................
  120 IF (IOFFS .EQ. 0) GO TO 125
      IOFFS=100/IOFFS
      GO TO 127
  125 IOFFS=1
  127 DO 140 J=1,256
      IBLADE=256*(IPAIR-1)+J*256/IOFFS+100000B
      CALL EXEC (3,19)
      CALL EXEC (1,17,IRPM,1,IBLADE)
      CALL EXEC (1,20,IBUFF,N,ICHAN,1)
      RBUFF=0.0
      DO 130 K=1,N
  130 RBUFF=RBUFF+FLOAT(IBUFF)/32752.
      DATA=RBUFF/IAVG
  140 SRVPT(J)=DATA
C     ...........................................................
C     .
C     .             OUTPUT TABLES/PRINT
C     .
C     ...........................................................
      WRITE (6,146)
  146 FORMAT(//,23X,"PACED SURVEY DATA",//)
      WRITE (6,148) SRVPT
  148 FORMAT(8(2X,F8.7))
  150 RPM=60/(IRPM*.0000032)
      WRITE (6,165) RPM
  165 FORMAT(/,20X,"COMPRESSOR RPM FOR THIS RUN WAS "
     CF7.2,/)
      GO TO 999
  195 WRITE (6,196) IPOSIT,IPAIR,PTDATA
  196 FORMAT(" THE DATA VALUE FOR POSITION ",I3," OF BLADE PAIR"
     *I2,"    IS    ",F10.7)
      GO TO 150
  999 RETURN
      END
```

Figure A-1. Unchanged Listing of Subroutine RPACE from Program & A2D (P. McCarville, Ref. 4)

```
127 DO 140 J=1,256
    IBLADE=256*(IPAIR-1)+J+256*(ICFS+100000)
    CALL EXEC (3,19)
    CALL EXEC (1,19,IRPM,1,IBLADE)
    CALL EXEC (1,20,IBUFF,N,ICHAN,0)
    RBUFF=0.0
    DO 130 K=1,N
130 RBUFF=RBUFF+FLOAT(IBUFF(K))/32768.
    DATA=RBUFF/IAVG
140 SRVPT(J)=DATA
```

Figure A-2. Corrected Statement of Subroutine RPACE from Program &A2D (P. McCarville, Ref. 4)

APPENDIX B

OUTPUT CHARACTERISTICS OF TYPE "A" AND TYPE "B" PROBES

The DPDS, measurements are carried out using two different kinds of pressure probes. The type "A" probe is essentially a total pressure probe (see Fig. 4). The general behavior of such a probe with respect to angle changes has been established for quite some time (Ref. 10). However, using a pneumatic equivalent probe to the "A" probe the output of the probe as a function of yaw angle was established with the probe mounted in the steady flow of a freejet.

Figure B-1 shows this dependence. The characteristics of this curve are a flat top, indicating an insensitivity of the probe to yaw angle changes of up to $\pm 20^{\circ}$ from the zero yaw angle position, and the steep but almost linear parts from -70° to -40° and $+40^{\circ}$ to $+70^{\circ}$. At yaw angles of -63° and $+63^{\circ}$ the probe reads static pressure and that happens independent of Mach number and pitch angle as long as the pitch angle does not exceed a range of -5° to about $+15^{\circ}$.

Figure 9 shows the output of the type "A" probe for different pitch angle settings but one Mach number only. It can be seen that pitch angles ranging from -15° to $+25^{\circ}$ at a 5° increment produce almost identical curves.

Figure 12 shows the output of the type "B" probe for the same Mach number and the same range of pitch angle. It can be seen that, compared to the "A" probe

probe does not have a flat top for a range of measurement close to the zero yaw angle (zero being the yaw angle where the probe is aligned with the flow). Instead it shows a clear and well-defined maximum in output for the zero yaw angle. It is also evident that the output depends very clearly on the pitch angle. The yaw angle where the probe reads static pressure is different for different pitch angles and Mach numbers. Different Mach numbers always show only one curve for the "A" probe (independent of pitch angle) while the "B" probe depends on changes of both Mach number and pitch angle .

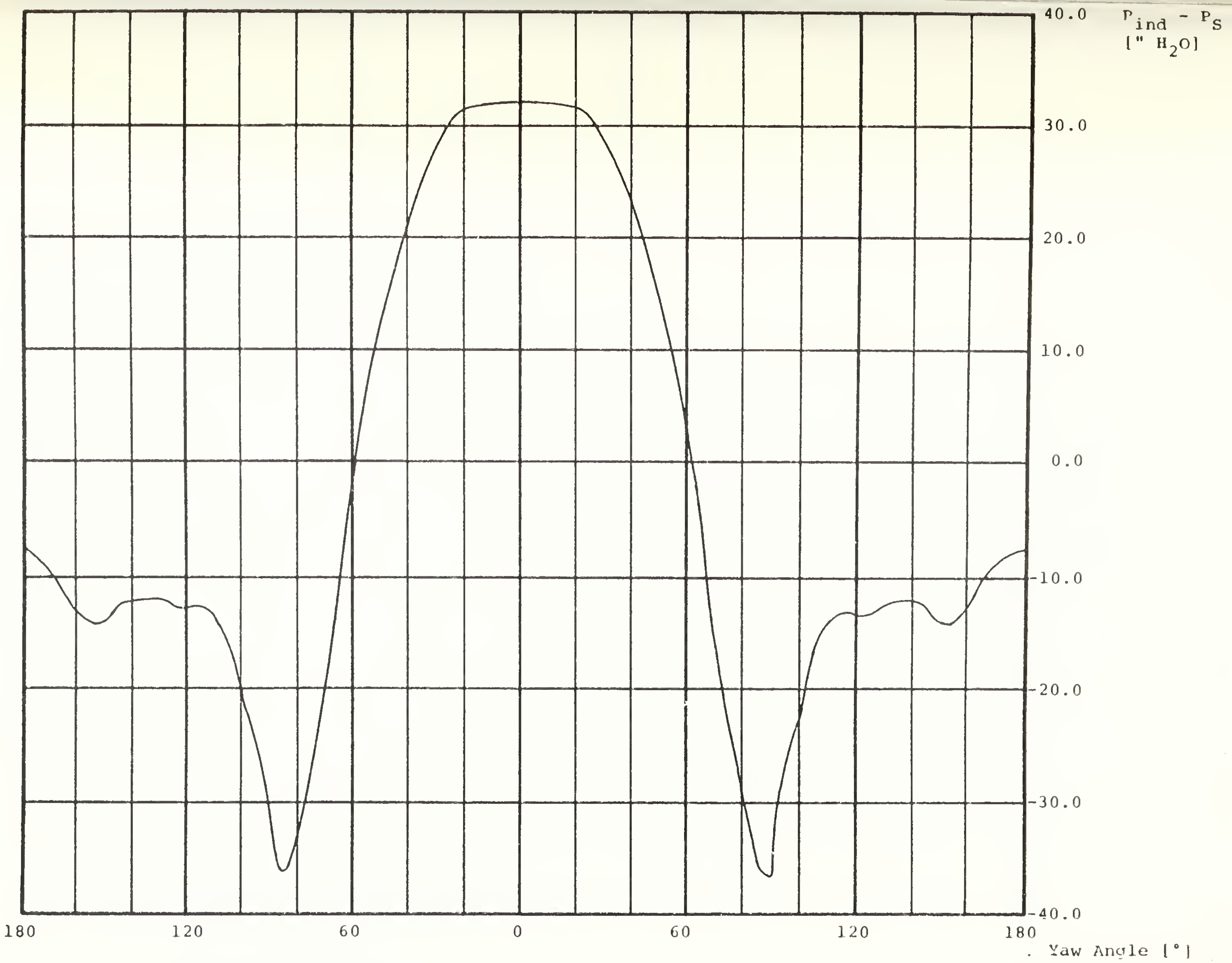


Figure B-1. Indicated Pressure Versus Yaw Angle for a Pneumatic Probe Equivalent to a Type A Probe. Dynamic Head = 32 " H20. Free Jet Flow, Zero Degrees Pitch Angle.

APPENDIX C

DATA ACQUISITION PROGRAMS &KALIB AND &YAW

The purpose of both programs--&YAW and &KALIB--is to acquire sufficient data for the calibration of either the type "A" or "B" probe. It has to be mentioned here that only one probe can be mounted in the center of the freejet at a time. It is therefore essential to establish identical conditions for the calibration of both probes.

Since the data reduction as outlined in 4.1 requires not only the knowledge of Mach number and pitch angle, but also the probe output characteristic as a function of yaw angle, data is acquired for different yaw angle settings. Here is the major difference between programs &YAW and &KALIB. While program &YAW requires the data acquisition at one specific yaw angle setting, &KALIB acquires data in a continuous mode for a range of 160° (-80° to +80°) in yaw angle.

However, program &YAW will be described first, since it is the more conventional one.

C-1. PROGRAM &YAW

Since parameters have to be changed during a calibration, the program has to work interactively with operator input. For each selected combination of Mach number and pitch angle data can be recorded for up to 31 probe yaw angle settings. For any of these settings the values of total pressure, Kulite reference pressure, probe yaw angle and Kulite pressure reading are acquired as the average of 10 data samples each. The pitch angle is keyed in by the operator prior to the measurement and the total temperature and the barometric pressure (static pressure since it is a freejet) are measured also. When the data for one yaw angle position is taken the operator is asked to have the probe moved to another yaw angle and initialize the data acquisition process again.

Once the data for all 31 yaw positions are taken, the operator is asked to key in a file name. The raw data from this calibration is then stored in a file with the name previously assigned.

In the next step absolute values for the total temperature (degrees Fahrenheit) and the static pressure (inches Hg) are calculated. File name, pitch angle, total temperature and static pressure are written on the line printer. The following DO-loop derives absolute values of the impact pressure (inches of water), the Kulite reference pressure (inches of water), the probe yaw angle (degrees), and the Kulite pressure output (inches of water) as a gage pressure. From these values a pressure coefficient c_p defined as

$$c_p = \frac{p_K + p_{ref} - p_s}{p_t - p_s}$$

where p_K = Kulite pressure

p_{ref} = Kulite reference pressure

p_t = total pressure

p_s = static pressure

is derived. All of these values are tabulated.

A plot of c_p vs yaw angle is produced automatically with the operator's choice of drawing a full grid or just the calibration result.

After this the program can either be stopped or started again for a different flow condition.

C-1 gives a flow chart, while C-2 is a program listing.

Externals: ABRT, CLEAR, CLOSE, CPLOT, CREAT, DRAW, FXD, LABEL, LDIR, LOCL, MOVE, OPEN, PLOTR, RMOTE, SCANR, SETAR, VIEWP, WINDW, WRITF

Variables	Type	Description
CDATA(32)	Real	Array containing pressure coefficients c_p
DATA(32,4)	Real	Array containing complete raw calibration data
ICR	Integer	Cartridge reference number
IDCB(144)	Integer	Data control block
IFILE(3)	Integer	Array containing file name
IGCB(192)	Integer	Graphic data control block
IL	Integer	Total number of words to be stored in raw data file (two words for one data value)
ISECU	Integer	Security code
ISIZE(2)	Integer	Array to specify file dimensions (1st word for number of records, 2nd for record length)
ITYPE	Integer	Type of data file
S T U V	Real	Sample readings of total pressure Kulite ref. pressure probe yaw angle Kulite output
W X Y Z	Real	Average values of total pressure Kulite ref. pressure probe yaw angle Kulite output

C-2. PROGRAM &KALIB

As stated earlier this program records probe data for more yaw positions than program &YAW. Once either the "A" or the "B" probe is mounted on the freejet and the desired flow condition (Mach number and pitch angle) is established, the actual pitch angle is keyed in, and single measurements of total temperature and pressure as well as Kulite reference pressure and barometric pressure are taken. The operator is then asked to start the data acquisition process for the Kulite pressure/yaw angle measurement. Simultaneously the operator has to signal that the probe shall be rotated in the freejet. While the probe is rotated from -80° to $+80^{\circ}$ in yaw at a constant rate of $\sim 3^{\circ}$/sec, the yaw position and the corresponding Kulite pressure reading is recorded alternatingly. When the whole range of yaw angle is finished, the flow conditions are recorded again and the probe is rotated backwards 160° with the same data acquisition process as before. Then the jet conditions are recorded a third time. All raw data is multiplied by its corresponding scaling factor. The total temperature is calculated in degrees Fahrenheit. A pressure coefficient as defined in C-1 is derived for all 300 points of measurement. The whole data array (contents are defined in the listing) is stored in one file with its name as operator input. A complete output of the file contents is printed. (Note: line printer must be set to "comp".)

The operator is then asked to specify the form of a plot of the just-acquired data. When the plot is completed the operator has the choice of stopping the program or performing another data acquisition for a different flow condition.

C-3 gives a flow chart of &KALIB while C-4 is a program listing.

Externals: ABRT, CLEAR, CLOSE, CPLOT, CREAT, DRAW, FXD, LABEL, LDIR, LOCL, MOVE, OPEN, PLOTR, RMOTE, SCANR, SETAR, VIEWP, WINDW, WRITF

Variables	Type	Description
CDATA(300)	Real	Array containing pressure coefficients c_p
DATA(2,320)	Real	Array containing complete raw calibration data
ICR	Integer	Cartridge reference number
IDCB(144)	Integer	Data control block
IFILE(3)	Integer	Array containing file name
IGCB(192)	Integer	Graphic data control block
IL	Integer	Total number of words to be stored in raw data file (two words for one data value)
ISECU	Integer	Security code
ISIZE(2)	Integer	Array to specify file dimensions (1st word for number of records, 2nd for record length)
ITYPE	Integer	Type of data file

By comparison of sets of data acquired with both programs for the same flow conditions, no difference was found between the results of the two programs.

Since program &KALIB offers much more overall information in even shorter time, it was used for the whole calibration of both probes with occasional comparisons between the two program results. Plots of the probe outputs vs yaw angle were produced and stored for each of the conditions to have an easy and clear idea of the probe's general behavior.

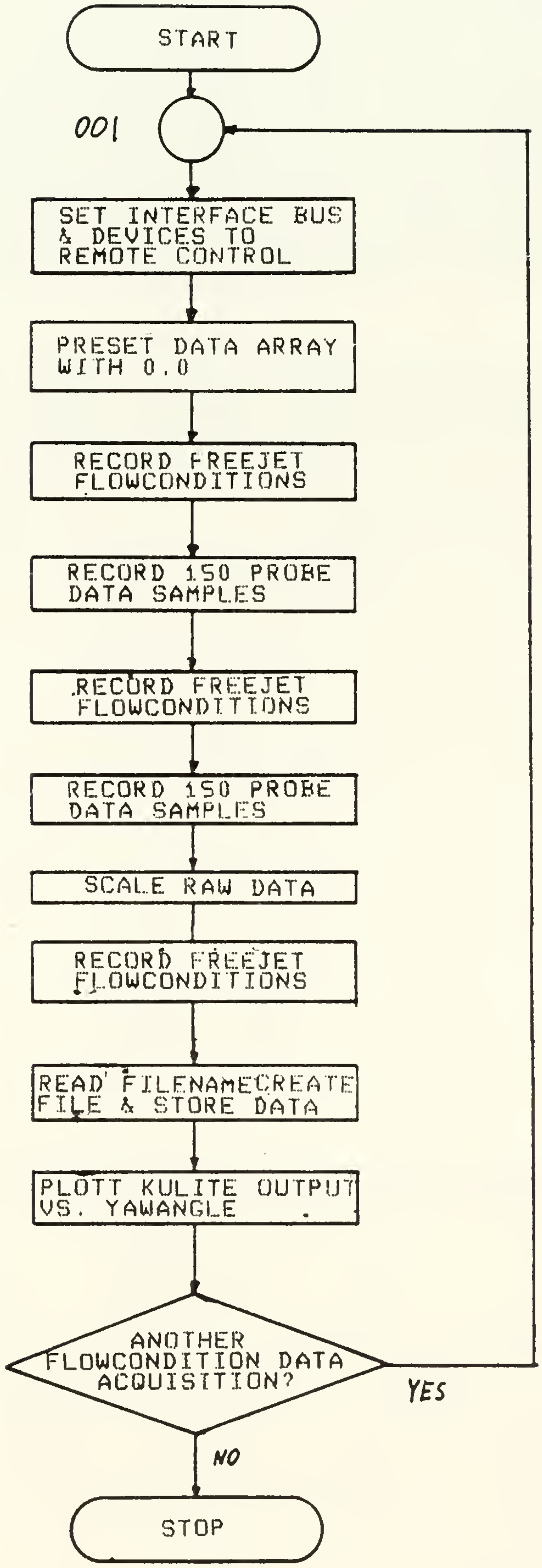


Figure C-1. Flow Chart of Data Acqusition Program & Yaw

```
&YAW   T=00004 IS ON CR00026 USING 00025 BLKS R=0000

FTN4,L
      PROGRAM YAW
      REAL      DATA(32,4),CDATA(32)
      DIMENSION IGCB(192),IDCB(144),IFILE(3),ISIZE(2)
      DATA      IDCBS /144/
      DATA      ISECU /0/
      DATA      ICR   /29/
      DATA      ITYPE /1/
      DATA      ISIZE /2,128/
      DATA      IL    /256/
C     ..............................................................
C     .
C     .  PROGRAM TO ACQUIRE DATA FOR THE CALBRATION OF A KULITE PROBE .
C     .  THIS PROGRAM TAKES DATA AT DEFINED YAW POSITIONS.
C     .  ONLY THE RAW DATA IS STORED.                                 .
C     .                                                               .
C     ..............................................................
  101 FORMAT (" READ PITCHANGLE FROM TERMINAL!")
  102 FORMAT (I4)
  103 FORMAT(" WHEN YOU ARE READY FOR THE "I4". MEASUREMENT, HIT CR !")
  104 FORMAT(" Pt tunnel= "F8.6" P ref.= "F8.6" Probe pos.= "F8.6" Kulit
     *e out= "F8.6)
  105 FORMAT (" ENTER THE FILE NAME YOU WANT THE RAW DATA TO BE STORED I
     * !")
  106 FORMAT(" IF YOU NEED A COMPLETE NEW FRAME, KEY YE !"/" ANY OTHER K
     *EY, IF NOT!")
  107 FORMAT (" IF YOU WANT ANOTHER SET OF DATA FOR A DIFFRENT PITCH ANG
     *E, KEY YES"/" ANYTHING ELSE, IF NOT!")
  149 FORMAT ((3A2))
  601 FORMAT (" RAW DATA ARE STORED IN FILE : "1X,3A2/)
  602 FORMAT (" Pitch ="I4" Tunnel Temp.="F8.2"P baro="F8.5//)
  603 FORMAT ("   #      YAW   Kulite out        P ref.    Pt tunnel"16X"C
     *p"//)
  604 FORMAT (I4,1X,F7.3,3(1X,F12.6),6X,F12.6)
  801 FORMAT("CA")
 1001 FORMAT("F1R7M3A1H0T3")
 1002 FORMAT("F1R7M3A0H0T3")
 1111 FORMAT("  # ="I5"IERR = "I5,F12.4)
 1301 FORMAT("B-PROBE     PITCH ="I4,10X"P BARO ="F7.3)
 1302 FORMAT("TUNNEL TEMPERATURE="F7.3,2X"FILE : "3A2)
 1303 FORMAT("      CP")
 1501 FORMAT("CA")

C     ..............................................................
C     .
C     .  DATA LOCATION IN THE DATA FILE :
C     .
C     .FOR I = 1 TO 31, I IS THE NUMBER OF THE YAW ANGLE.
C     .FOR EACH OF THESE YAW ANGLES THE ARRAY CONTAINS THE FOLLOWING
C     .VALUES IN THE GIVEN ORDER:
C     .
C     .            1               2                  3               4
C     .# 1 Pt tunnel     P ref. Kulite    Probe position   Kulite press.
C     .# 2     "               "               "               "
C     .  :     "               "               "               "
C     .  :     "               "               "               "
C     .#31     "               "               "               "
C     .
C     .DATA(32,1)  contains  pitchangle   input from terminal
C     .DATA(32,2)  contains  Tt tunnel    read from scanr #2  ch 6
C     .DATA(32,3)  contains  P baro       read from scanr #1  ch 25
C     .
C     ..............................................................
  001 CALL  ABRT(7,2)
      CALL  RMOTE( 8)
      CALL  RMOTE(10)
      CALL  RMOTE(15)
      WRITE (8,801)
      WRITE (10,1001)
      WRITE (15,1501)

C     ..............................................................
C     .
C     .  PRESET DATA ARRAY WITH 0.0 !
C     .
C     ..............................................................

      DO 002 I   = 1,32,1
```

Figure C-2. Listing of Calibration Data Acquisition Program &YAW. (Continued on next page.)

```
      DATA(I,1)  = 0.0
      DATA(I,2)  = 0.0
      DATA(I,3)  = 0.0
002   DATA(I,4)  = 0.0
      DATA(32,2) = SCANR(15,06,01)
      DATA(32,3) = SCANR(08,25,01)
      WRITE(1,101)
      READ (1,102) DATA(32,1)
      WRITE(10,1002)
      DO 010 I = 1,31,1
003   WRITE (1,103) I
      READ  (1,149) IDUM
      IF    (IDUM .NE. 2H   ) GOTO 003
      W          = 0
      X          = 0
      Y          = 0
      Z          = 0

      DO 008 J   = 1,10,1
      S          = SCANR(15,20,01)
      W          = W + S
      T          = SCANR(15,21,01)
      X          = X + T
      U          = SCANR(15,22,01)
      Y          = Y + U
      V          = SCANR(15,23,01)
008   Z          = Z + V
      DATA(I,1) = W/10
      DATA(I,2) = X/10
      DATA(I,3) = Y/10
      DATA(I,4) = Z/10
010   WRITE(1,104) (DATA(I,J),J= 1,4,1)
      WRITE(1,105)
      READ  (1,149) IFILE
      CALL CREAT (IDCB,IERR,IFILE,ISIZE,ITYPE,ISECU,ICR,IDCBS)
      JJ = 1
      IF (IERR .LT. 0 ) WRITE(1,1111) JJ,IERR
      CALL OPEN  (IDCB,IERR,IFILE,IOPTN,ISECU,ICR,IDCBS)
      JJ = 2
      IF (IERR .LT. 0 ) WRITE(1,1111) JJ,IERR
      CALL WRITF (IDCB,IERR,DATA,IL)
      JJ = 3
      IF (IERR .LT. 0 ) WRITE(1,1111) JJ,IERR
      CALL CLOSE (IDCB,IERR,0)
      JJ = 4
      IF (IERR .LT. 0 ) WRITE (1,1111) JJ,IERR
      DATA(32,2) = 32.6149 + 34727.9 * DATA(32,2)
      DATA(32,3) = DATA(32,3) * 10000
      WRITE(6,601) IFILE
      WRITE(6,602)DATA(32,1),DATA(32,2),DATA(32,3)
      WRITE(6,603)
      DO 020  I = 1,31,1
      DATA(I,1) = DATA(I,1) * 10000
      DATA(I,1) = DATA(I,1) * 10
      DATA(I,2) = DATA(I,2) * 10000
      DATA(I,3) = DATA(I,3) * 10000
      DATA(I,4) = DATA(I,4) * 10000
      CDATA(I) = (DATA(I,4) + DATA(I,2)) / DATA(I,1)
020   WRITE(6,604) I,DATA(I,3),DATA(I,4),DATA(I,2),DATA(I,1),CDATA(I)

      CALL CLEAR (7,1)
      CALL LOCL  (7)
      CALL PLOTR (IGCB,2,1,13)
      CALL SETAR (IGCB,1.5)
      CALL VIEWP (IGCB,30.,110.,20.,70.0)
      CALL WINDW (IGCB,-80.,80.,-1.0,1.0)
      CALL FXD   (IGCB,1)
      WRITE(1,106)
      READ (1,149) IDUM
      IF(IDUM.EQ.2HYE)  CALL LGRID (IGCB,-5.,0.5,0.0,0.0,4.0,1.0,1.0)
      CALL MOVE  (IGCB,DATA(1,3),CDATA(1))
      DO  040 I=1,31,1
040   CALL DRAW  (IGCB,DATA(I,3),CDATA(I))
      CALL VIEWP  (IGCB,0.,150.,0.,100.)
      CALL WINDW  (IGCB,0.,150.,0.,100.)
      CALL MOVE  (IGCB,22.,15.)
      CALL CPLOT(IGCB,-8.,0.,0)
      CALL LABEL (IGCB)
      WRITE(13,1301)DATA(32,1),DATA(32,3)
      CALL MOVE  (IGCB,22.,10.)
```

Figure C-2. Listing of Calibration Data Acquisition Program &YAW. (Continued on next page.)

```
      CALL CPLOT (IGCB,-8.,0.,0.)
      CALL LABEL (IGCB)
      WRITE (13,1302) DATA(32,2),IFILE
      CALL MOVE  (IGCB,18.0,20.)
      CALL CPLOT (IGCB,-8.,0.,0.0)
      CALL LDIR  (IGCB,+1.57)
      CALL LABEL (IGCB)
      WRITE (13,1303)
      WRITE(1,107)
      READ(1,149) IDUM
      IF (IDUM .EQ. 2HYE) GOTO 1
      STOP 7777
      END
      REAL FUNCTION SCANR (LU,ICHAN,K)
C     ..................................................................
C     .                                                                .
C     .  Close relay ICHAN on scanner LU and read the instrument       .
C     .  indicated by K.                                               .
C     .  Author:     Robert N. Geopfarth                               .
C     .  Date:       February 31, 1979                                 .
C     .  Detailed program description is available in TXCO log;  the  .
C     .  variables are:                                                .
C     .  LU      ...   LU# of desired scanner (8 or 15).               .
C     .  ICHAN   ...   Scanner channel (integer).                      .
C     .  IC      ...   Scanner channel (ASCII).                        .
C     .  K       ...   Instrument code ( DVM = 1 / Counter = 2 ).      .
C     .                                                                .
C     ..................................................................
     *, Closes scanner and reads DVM, counter.  "
  101 FORMAT (A2)
  801 FORMAT ("C")
 1001 FORMAT ("T3T3")
 1201 FORMAT ("T")
 1501 FORMAT ("C")

      WRITE ( 8, 801)
      WRITE (15,1501)
      IC = ICON(ICHAN,0)
      WRITE (LU, 101) IC
      GO TO (01,02) K

   01 CALL TRIGR (10)
      READ  (10,    *) DUM
      CALL TRIGR (10)
      READ  (10,    *) SCANR
      GO TO 03

   02 WRITE (12,1201)
      READ  (12,    *) SCANR

   03 WRITE (LU, 801)
      RETURN
      END
      INTEGER FUNCTION ICON(I,N)
      IC=I+N
      IF(IC.LT.10) GO TO 100
      CALL CODE
      WRITE(ICON,60)IC
60    FORMAT(I2)
      RETURN
100   ICON=IC+30060B
      RETURN
      END
```

Figure C-2. Listing of Calibration Data Axquisition Program &YAW.

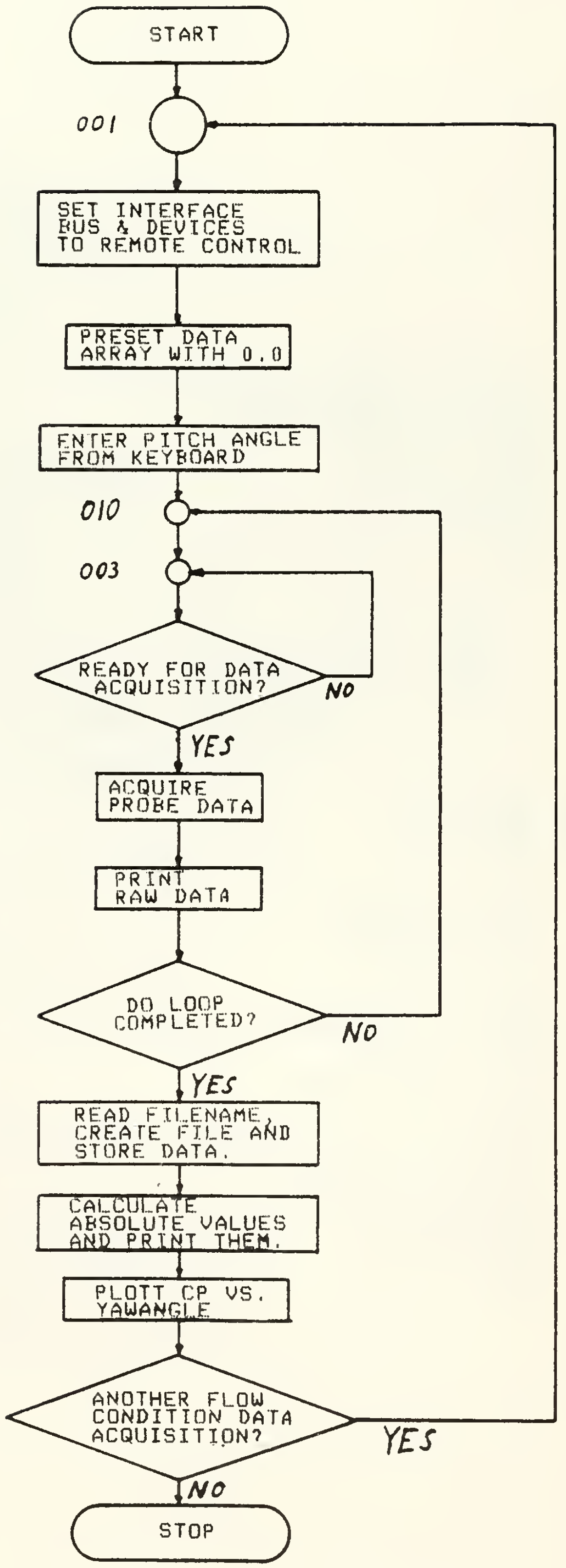


Figure C-3. Flow Chart of Data Acquisition Program & KALIB

```
KALIB T=00004 IS ON CR00026 USING 00042 BLKS R=0000

FTN4,L
      PROGRAM KALIB
      REAL DATA(2,320),CDATA(300)
      DIMENSION IGCB(192),IDCB(144),IFILE(3),ISIZE(2)
      DATA  IDCRS /144/
      DATA  ISECU /0/
      DATA  ICR   /27/
      DATA  ITYPE /1/
      DATA  ISIZE /10,128/
      DATA  IL    /1280/

C     ..................................................................
C     .                                                                .
C     .  PROGRAM TO ACQUIRE DATA FOR THE CALIBRATION OF A KULITE PROBE. .
C     .                                                                .
C     ..................................................................
  101 FORMAT(" READ PITCHANGLE FROM TERMINAL:")
  102 FORMAT( "WHEN YOU ARE READY FOR THE MEASUREMENT, HIT CR !")
  103 FORMAT( "FIRST RANGE COMPLETED!")
  104 FORMAT("  WHEN YOU ARE READY TO MOVE THE PROBE BACKWARDS,KEY CR!")
  105 FORMAT(" ENTER THE FILE NAME YOU WANT THE RAW DATA TO BE STORED IN
     * :")
  106 FORMAT(" IF YOU NEED A COMPLETE NEW FRAME, KEY YE !"/" ANY OTHER K
     *EY,IF NOT!")
  107 FORMAT(" IF YOU WANT ANOTHER SET OF DATA FOR A DIFFRENT PITCH ANGL
     *E, KEY YES"/" ANYTHING ELSE,IF NOT!")
  149 FORMAT((3A2))
  601 FORMAT(" RAW DATA ARE STORED IN FILE :"1X,3A2,15X"PITCH =  "I4/)
  602 FORMAT("         TUNNEL TEMP. DEG. F  TUNNEL PRESS. INCHES H2O   K R
     *EF PRESS. INCHES H2O         P BARO INCHES HG")
  603 FORMAT(4(7X,F19.7),5X"BEFORE READINGS"/)
  604 FORMAT(4(7X,F19.7),5X"BETWEEN READINGS"/)
  605 FORMAT(4(7X,F19.7),5X"AFTER READINGS"/)
  606 FORMAT(4(7X,F19.7),5X"AVERAGE VALUES"/)
  607 FORMAT("  # YAWANG KULITEOUT    CP    # YAWANG KULITEOUT    CP    #
     *YAWANG KULITEOUT    CP    # YAWANG KULITEOUT    CP    # YAWANG KULIT
     *EOUT    CP")
  608 FORMAT(I3,1X,F6.3,2X,F8.5,1X,F5.3,4(I4,1X,F6.3,2X,F8.5,1X,F5.3))
  609 FORMAT(1H1)
  801 FORMAT("CA")
 1001 FORMAT("F1R7M3A1H0T3")
 1002 FORMAT("F1R7M3A0H0T3")
 1111 FORMAT("  # ="I5"IERR = "I5,F12.4)
 1301 FORMAT("B-PROBE  PITCH ="I4,1X"P BARO ="F7.3,1X"FILE ="3A2)
 1302 FORMAT("TUNNEL TEMPERATURE="F7.3" TUNNEL PRESS.="F7.3)
 1303 FORMAT("KULITE OUTPUT (INCHES H2O)")
 1501 FORMAT("CA")
C     ..................................................................
C     .DATA LOCATION IN THE DATA FILE :                                 .
C     .                                                                .
C     .   LOCATION IN FILE :              CONTAINS :                    .
C     .FOR I = 1 TO 300  DATA(1,I)        YAW POSITION                  .
C     .FOR I = 1 TO 300  DATA(2,I)        KULITE PRESS. OUTPUT          .
C     .                                                                .
C     .LOCATION IN FILE: CONTAINS:         READ FROM:                   .
C     .                                                                .
C     .DATA(1,301)       T total tunnel   Ch# 6 Scanr.# 2              .
C     .DATA(2,301)       P total tunnel   Ch#20 Scanr.# 2  b e f o r e  .
C     .DATA(1,302)       K ref. press.    Ch#21 Scanr.# 2  r e a d i n g .
C     .DATA(2,302)       Barom. press.    Ch#25 Scanr.# 1              .
C     .                                                                .
C     .DATA(1,303)       T total tunnel   Ch# 6 Scanr.# 2              .
C     .DATA(2,303)       P total tunnel   Ch#20 Scanr.# 2  b e t w e e n .
C     .DATA(1,304)       K ref. press.    Ch#21 Scanr.# 2  r e a d i n gs.
C     .DATA(2,304)       Barom. press.    Ch#25 Scanr.# 1              .
C     .                                                                .
C     .DATA(1,305)       T total tunnel   Ch# 6 Scanr.# 2              .
C     .DATA(2,305)       P total tunnel   Ch#20 Scanr.# 2  a f t e r    .
C     .DATA(1,306)       K ref. press.    Ch#21 Scanr.# 2  r e a d i n g .
C     .DATA(2,306)       Barom. press.    Ch#25 Scanr.# 1              .
C     .                                                                .
C     .DATA(1,318)       T total tunnel     A v e r a g e               .
C     .DATA(2,318)       P total tunnel     V a l u e s                 .
C     .DATA(1,319)       K ref. press.      F r o m  t h r e e          .
C     .DATA(2,319)       Barom. press.      r e a d i n g s  a b o v e  .
C     .                                                                .
C     .DATA(1,320)       Pitch angle         Terminal                  .
C     .                                                                .
```

Figure C-4. Listing of Calibration Data Acquisition Program &KALB.
(Continued on next page.)

```
C     ..........................................................................


  001 CALL  ABRT(7,2)
      CALL  RMOTE( 8)
      CALL  RMOTE(10)
      CALL  RMOTE(15)

      WRITE (8,801)
      WRITE (10,1001)
      WRITE (15,1501)
C     ........................................................................
C     :                                                                      :
C     : PRESET NEW DATA ARRAY WITH 0.0                                       :
C     :                                                                      :
C     ........................................................................

      DO 002 I  = 1,320,1
      DATA(1,I) = 0.0
  002 DATA(2,I) = 0.0
      WRITE(1,101)
      READ (1,  *) DATA(1,320)
      DATA(1,301) = SCANR(15,06,01)
      DATA(2,301) = SCANR(15,20,01)
      DATA(1,302) = SCANR(15,21,01)
      DATA(2,302) = SCANR(08,25,01)
      WRITE(10,1002)
  005 WRITE(1,102)
      READ (1,149) IDUM
      IF ( IDUM .NE.2H   ) GOTO 005
      DO 010 I = 1,150,1
      DATA(1,I) = SCANR(15,22,01)
  010 DATA(2,I) = SCANR(15,23,01)
      DATA(1,303) = SCANR(15,06,01)
      DATA(2,303) = SCANR(15,20,01)
      DATA(1,304) = SCANR(15,21,01)
      DATA(2,304) = SCANR(08,25,01)
      WRITE(1,103)
  015 WRITE(1,104)
      READ(1,149) IDUM
      IF ( IDUM .NE. 2H   ) GOTO 015
      DO 018 I = 151,300,1
      DATA(1,I) = SCANR(15,22,01)
  018 DATA(2,I) = SCANR(15,23,01)
      DATA(1,305) = SCANR(15,06,01)
      DATA(2,305) = SCANR(15,20,01)
      DATA(1,306) = SCANR(15,21,01)
      DATA(2,306) = SCANR(08,25,01)
      CALL CLEAR(7,1)
      CALL LOCL (7)
      DO  019 I = 1,319,1
      DATA(1,I) = DATA(1,I) * 10000
  019 DATA(2,I) = DATA(2,I) * 10000
      DO  020 I = 301,305,2
      DATA(1,I) = 32.6149 + 3.47279 * DATA(1,I)
  020 DATA(2,I) = DATA(2,I) * 10
      DATA(1,318) = (DATA(1,301)+DATA(1,303)+DATA(1,305))/3
      DATA(2,318) = (DATA(2,301)+DATA(2,303)+DATA(2,305))/3
      DATA(1,319) = (DATA(1,302)+DATA(1,304)+DATA(1,306))/3
      DATA(2,319) = (DATA(2,302)+DATA(2,304)+DATA(2,306))/3
      DO 021 I = 1,300,1
  021 CDATA(I)=  (DATA(2,I)+DATA(1,319)) /DATA(2,318)
      WRITE(1,105)
      READ (1,149) IFILE
      CALL CREAT (IDCB,IERR,IFILE,ISIZE,ITYPE,ISECU,ICR,IDCBS)
      JJ = 1
      IF (IERR .LT. 0 ) WRITE(1,1111) JJ,IERR
      CALL OPEN  (IDCB,IERR,IFILE,IOPTN,ISECU,ICR,IDCBS)
      JJ = 2
      IF (IERR .LT. 0 ) WRITE(1,1111) JJ,IERR
      CALL WRITF (IDCB,IERR,DATA,IL)
      JJ = 3
      IF (IERR .LT. 0 ) WRITE(1,1111) JJ,IERR
      CALL CLOSE (IDCB,IERR,0)
      JJ = 4
      IF (IERR .LT. 0 ) WRITE (1,1111) JJ,IERR
      WRITE(6,601) IFILE,DATA(1,320)
      WRITE(6,602)
      WRITE (6,603) DATA(1,301),DATA(2,301),DATA(1,302),DATA(2,302)
      WRITE (6,604) DATA(1,303),DATA(2,303),DATA(1,304),DATA(2,304)
```

Figure C-4. Listing of Calibration Data Acquisition Program &KALIB. (Continued on next page.)

```
      WRITE (6,605) DATA(1,305),DATA(2,305),DATA(1,306),DATA(2,306)
      WRITE (6,606) DATA(1,318),DATA(2,318),DATA(1,319),DATA(2,319)
      WRITE(6,607)
      DO 030  I =1,60,1
      J     = I + 60
      II    = J + 60
      JJ    = II+ 60
      III   = JJ+ 60
030   WRITE(6,608)I,DATA(1,I),DATA(2,I),CDATA(I),J,DATA(1,J),DATA(2,J),C
     *DATA(J),II,DATA(1,II),DATA(2,II),CDATA(II),JJ,DATA(1,JJ),DATA(2,JJ
     *),CDATA(JJ),III,DATA(1,III),DATA(2,III),CDATA(III)

      WRITE(6,609)
      CALL PLOTR (IGCB,2,1,13)
      CALL SETAR (IGCB,1.5)
      CALL VIEWP (IGCB,30.,110.,20.,68.0)
      CALL WINDW (IGCB,-80.,80.,-160.00,160.0)
      CALL FXD   (IGCB,1)
      WRITE(1,106)
      READ (1,149) IDUM
      IF(IDUM.EQ.2HYE)  CALL LGRID (IGCB,-5.,10.,0.0,0.0,4.0,2.0,1.0)
      CALL MOVE  (IGCB,DATA(1,1),DATA(2,1))
      DO  040 I=1,300,1
040   CALL DRAW  (IGCB,DATA(1,I),DATA(2,I))
      IF(IDUM .NE. 2HYE) GOTO  050
      CALL VIEWP  (IGCB,0.,150.,0.,100.)
      CALL WINDW  (IGCB,0.,150.,0.,100.)
      CALL MOVE  (IGCB,22.,15.)
      CALL CPLOT(IGCB,-8.,0.,0)
      CALL LABEL (IGCB)
      WRITE(13,1301)DATA(1,320),DATA(2,319),IFILE
      CALL MOVE  (IGCB,22.,10.)
      CALL CPLOT (IGCB,-8.,0.,0.)
      CALL LABEL (IGCB)
      WRITE (13,1302) DATA(1,318),DATA(2,318)
      CALL MOVE  (IGCB,18.0,20.)
      CALL CPLOT (IGCB,-8.,0.,0.0)
      CALL LDIR  (IGCB,+1.57)
      CALL LABEL (IGCB)
      WRITE (13,1303)
050   CONTINUE
      WRITE(1,107)
      READ(1,149) IDUM
      IF (IDUM .EQ. 2HYE) GOTO 1
      STOP 7777
      END
      REAL FUNCTION SCANR (LU,ICHAN,K)
C     ...............................................................
C     .                                                             .
C     .  Close relay ICHAN on scanner LU and read the instrument    .
C     .  indicated by K.                                            .
C     .  Author:    Robert N. Geopfarth                             .
C     .  Date:      February 31, 1979                               .
C     .  Detailed program description is available in TXCO log;  the .
C     .  variables are:                                             .
C     .  LU      ...   LU# of desired scanner (8 or 15).            .
C     .  ICHAN   ...   Scanner channel (integer).                   .
C     .  IC      ...   Scanner channel (ASCII).                     .
C     .  K       ...   Instrument code ( DVM = 1 / Counter = 2 ).   .
C     .                                                             .
C     ...............................................................
     *, Closes scanner and reads DVM, counter.  "
  101 FORMAT (A2)
  801 FORMAT ("C")
 1001 FORMAT ("T3T3")
 1201 FORMAT ("T")
 1501 FORMAT ("C")

      WRITE ( 8, 801)
      WRITE (15,1501)
      IC = ICON(ICHAN,0)
      WRITE (LU, 101) IC
      GO TO (01,02) K

   01 CALL TRIGR (10)
      READ  (10,   *) DUM
      CALL TRIGR (10)
      READ  (10,   *) SCANR
      GO TO 03
```

Figure C-4. Listing of Calibration Data Acquisition Program &KALIB. (Continued on next page.)

```
     02 WRITE (12,1201)
        READ  (12,    *) SCANR

     03 WRITE (LU, 801)
        RETURN
        END
        INTEGER FUNCTION ICON(I,N)
        IC=I+N
        IF(IC.LT.10) GO TO 100
        CALL CODE
        WRITE(ICON,60)IC
 60     FORMAT(I2)
        RETURN
 100    ICON=IC+30060B
        RETURN
        END
```

Figure C-4. Listing of Calibration Data Acquisition Program &KALIB.

APPENDIX D

DATA REDUCTION PROGRAMS &REST8 AND &REST9

The programs &REST8 and &REST9 are in principal the same and follow the same logic. They are used to approximate the Mach number--or X --and the pitch angle, ϕ, as functions of the two independent variables β and γ (see 4.5). The software used to work out the approximations is described explicitly in Ref. 6. Basis for the approximation is the data as shown in Table V. This data is stored as a 10 by 54 array in a data file ABNEW2 on cartridge 26. The data is read into a 10 by 54 array from file ABNEW2 by both programs. Since the approximation itself is carried out in external subroutines, the necessary variables are contained in a common block. &REST8 thus contains β (BETA), γ (GAMMA) and X (XVEL) while &REST9 contains β (BETA), γ (GAMMA) and PHI (pitch angle in radians). As approximations of different order are possible for both variables β and γ, the orders of the approximations are increased from one to six in a DO-loop for both variables, resulting in a total of 36 combinations.

For all combinations the set of coefficients is printed out and also an array (6,9) for all errors (see 4.5) resulting from this particular approximation. When the whole DO-loop is worked out, the operator has to decide what order of approximation he wants to use for the application of the probes. In general lower order polynomials should be preferred against higher ones, although the latter promise the smaller overall error. The criterion for the decision should be the error distribution within a range of Mach number and pitch angle which will be the one of the most common application.

Once this decision has been made, the operator inputs the desired orders of polynomials. The corresponding coefficients are then recalculated and the operator is asked for a file name under which he wants to have these coefficients stored in a 7 by 7 array.

As programs &REST8 and &REST9 are in principal identical, only one flow chart (Fig. D-1) is given, and a listing of program &REST9 is given in (Fig. D-2).

Labeled common blocks:

Common block identifier	Variable
MATRX	A, B
SUMME	BETA, GAMMA, XVEL (or PHI)

Variables	Type	Description
A(49,49)	Real	System matrix used for the 3-D approximation of XVEL (or PHI) as function of BETA and GAMMA (see Ref. 6)
B(49)	Real	Right hand side vector of 3-D approximation (see Ref. 6)
BETA(16,16)	Real	Beta--pressure coefficient
COEFF(7,7)	Real	Approximation coefficients array

Variables	Type	Description
D(10,54)	Real	Calibration data array
GAMMA	Real	Gamma--pressure coefficient
ICR	Integer	Cartridge reference number
IDCB(144)	Integer	Data control block
IFILE(3)	Integer	Array containing file name
ISECU	Integer	Security code
ISIZE(2)	Integer	Array to specify file dimensions (1st word for number of records, 2nd for record length)
ITYPE	Integer	Type of data file
NMACH	Real	Number of different Mach number settings during the calibration
NPITCH	Real	Number of different pitch angle settings during the calibration
PHI(16,16)	Real	Array containing the actual pitch angle settings during the calibration
PI	Real	3.14593
R(16)	Real	Array containing the individual errors between calibration data and calculated values
SUM	Real	Calculated value of XVEL or PHI (depending on program)
XVEL(16,16)	Real	Array containing the actual Mach number (X) settings during the calibration

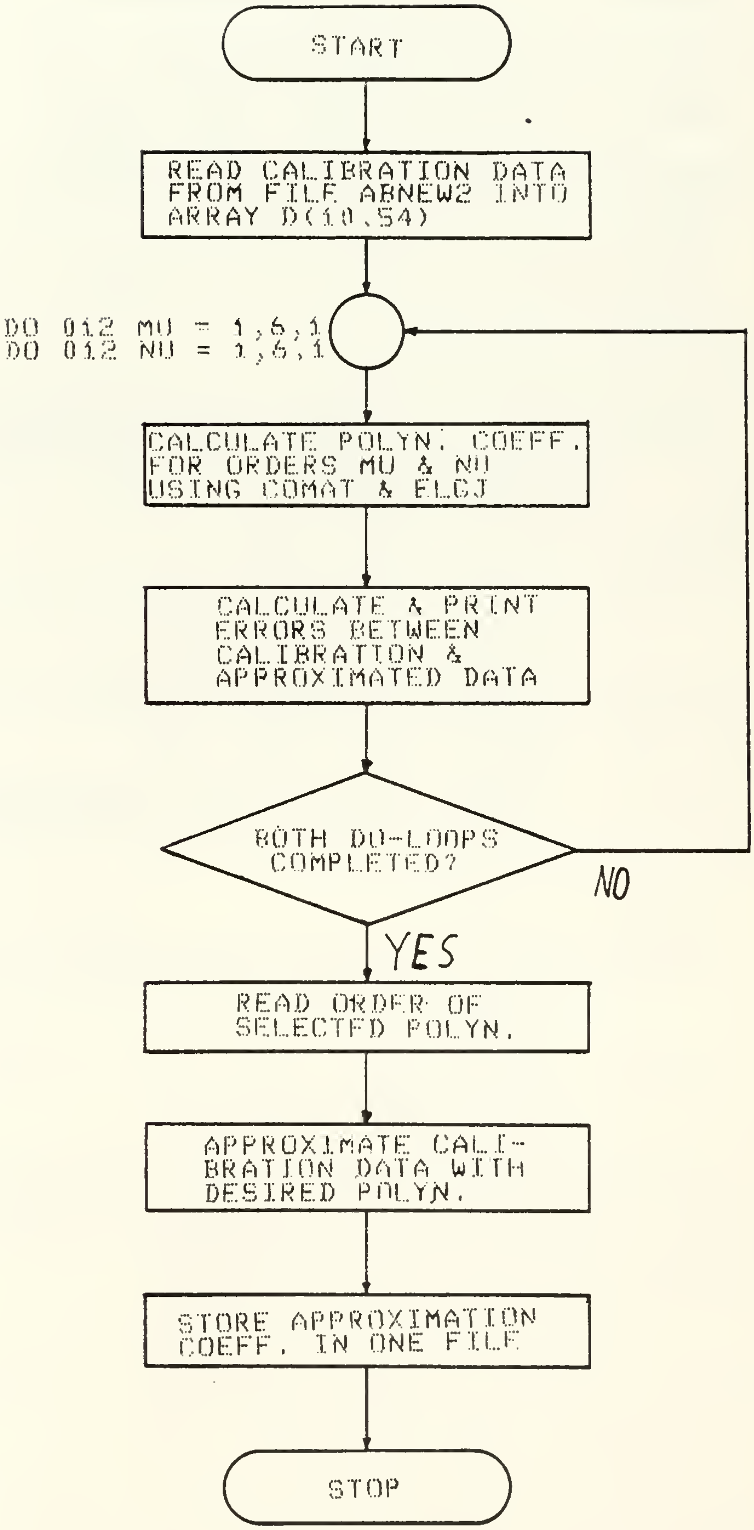


Figure D-1. Flow Chart of Data Reduction Program & REST 8/9

```
&REST9 T=00004 IS ON CR00026 USING 00024 BLKS R=0000

FTN4,L
      PROGRAM REST9 (3,99)
C     .................................................................
C     .                                                               .
C     .     This is program REST9 !                                   .
C     .                                                               .
C     . It reads file ABNEW2 (26) which contains calibration data from.
C     . the new A- and B-probe ( 0.062" o.d., screen with holes).     .
C     . It then approximates the pitchangle Phi as a function of      .
C     . beta and gamma by different order of polynominals .           .
C     . The results of all approximations are printed for evaluation  .
C     . purposes, but only one set of coefficients is stored.         .
C     . The software used for the polynominal approximation is        .
C     . available in the Turbopropulsion Laboratory Binary Library    .
C     . (TPLBL). See NPS67-80-001CR for further reference.            .
C     .                                                               .
C     .                                                               .
C     .................................................................
      COMMON / MATRX / A,B
      COMMON / SUMME / BETA,GAMMA,PHI
      REAL A(49,49),B(49),COEFF(7,7),D(10,54)
      INTEGER IDCB(144),IFILE(3),ISIZE(2)
      REAL BETA(16,16),GAMMA(16,16),PHI(16,16)
      REAL R(16)
      DATA PI     /3.141593/
      DATA IFILE /2HAB,2HNE,2HW2/
      DATA ISECU /0/
      DATA ICR   /26/
      DATA ITYPE /1/
      DATA ISIZE /3,128/
      DATA IDCBS /144/
  101 FORMAT (" SELECT SET OF COEFFICIENTS FOR BEST RESULTS !"/" ENTER M
     *ORDER AND NORDER NOW :")
  149 FORMAT(""((3A2)))
  601 FORMAT (///" COEFFICIENTS FOR THE CALIBRATION SURFACE STORED IN FI
     *LE :"3A2/)
  602 FORMAT ((3X,10(11X,I2)))
  603 FORMAT (1X,I2,7(2X,F11.6))
  604 FORMAT (///" ERRORS AT EACH POINT (DEGREES)"/)
  605 FORMAT ((3X,16(6X,I2)))
  606 FORMAT (1X,I2,16(1X,F7.3)/3(3X,16(1X,F7.3)/))
 1111 FORMAT ( " STATEMENT # "I4 " ERROR # "I4 " ENCOUNTERED !")
      LI = LOGLU(I)
C     .................................................................
C     .                                                               .
C     .  READ DATA FILE ABNEW2 FROM CARTRIDGE 26 INTO ARRAY D(10,54). .
C     .                                                               .
C     .................................................................
      CALL OPEN (IDCB,IERR,IFILE,IOPTN,ISECU,ICR,IDCBS)
      JJ = 1
      IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
      CALL READF (IDCB,IERR,D,1080,LEN,1)
      JJ = 2
      IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
      CALL CLOSE (IDCB,IERR,0)
      JJ = 3
      IF ( IERR   LT.  0 ) WRITE (LI,1111) JJ,IERR

      IJ           = 0
      DO 001  I    = 1,6,1
      DO 001  J    = 1,9,1
      IJ           = IJ + 1
      IF (J .EQ. 6) D(4,IJ) = D(4,IJ) + 0.00001
      PHI  (I,J) = D(4,IJ) * PI / 180.0
      BETA (I,J) = D(8,IJ)
  001 GAMMA(I,J) = D(9,IJ)


      NMACH        = 6
      NPITCH       = 9

  002 CONTINUE


C     .................................................................
C     .                                                               .
C     .  CALCULATE CALIBRATION SURFACE COEFFICIENTS.                  .
C     .
```

Figure D-2. Listing of Reduced Data Approximation Program &REST9. (Continued on next page.)

```
C       IJI.........................................................................
        IJI           = 0
        DO   011 MU = 1,6,1
        DO   011 NU = 1,6,1
        MORDER        = MU
        NORDER        = NU
    003 CONTINUE
        DO 004 I      = 1,7,1
        DO 004 J      = 1,7,1
    004 COEFF(I,J) = 0.0
        M             = MORDER+1
        N             = NORDER+1
        CALL COMAT (A,B,M,N,NMACH,NPITCH)
        NEQUS         = M*N
        CALL ELGJ (NEQUS)
        I1            = 0
        DO 005    I = 1,M,1
        DO 005    J = 1,N,1
        I1            = I1+1
    005 COEFF(I,J) = B(I1)
        IF ( IJI  .NE.  1  ) GOTO  006
        IFILE(1)      = 2HMI
        IFILE(2)      = 2HST
        IFILE(3)      = 2HFI
        CALL CREAT (IDCB,IERR,IFILE,ISIZE,ITYPE,ISECU,ICR,IDCBS)
        JJ = 4
        IF ( IERR  .GT.  0 ) WRITE (LI,1111) JJ,IERR
        CALL OPEN  (IDCB,IERR,IFILE,IOPTN,ISECU,ICR,IDCBS)
        JJ = 5
        IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
        CALL WRITF (IDCB,IERR,COEFF,98)
        JJ = 6
        IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
        CALL CLOSE (IDCB,IERR,0)
        JJ = 7
        IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
        WRITE (6,601) IFILE
    006 CONTINUE
        WRITE (6,602) (J,J=1,N,1)
        DO 007 I=1,M,1
    007 WRITE (6,603) I,(COEFF(I,J),J=1,N,1)
        WRITE (6,602) (J,J=1,N,1)
C       ...................................................................
C       .                                                                 .
C       .  CALCULATE ERRORS FOR ALL MACHNUMBER PITCHANGLE COMBINATIONS.  .
C       .                                                                 .
C       ...................................................................
        WRITE (6,604)
        WRITE (6,605) (J,J=1,NPITCH,1)
        DO 010   I  = 1,NMACH,1
        DO 009   J  = 1,NPITCH,1
        SUM           = 0.
        DO 008   I1 = 1,M,1
        DO 008   J1 = 1,N,1
    008 SUM=SUM+(COEFF(I1,J1)*GAMMA(I,J)**(J1-1))*BETA (I,J)**(I1-1)
    009 R(J)          = (PHI(I,J) - SUM) * 180.0 / PI
    010 WRITE (6,606) I,(R(J),J=1,NPITCH,1)
        WRITE (6,605) (J,J=1,NPITCH,1)
        IF (IJI .EQ. 1 ) GOTO 012
    011 CONTINUE
        WRITE (LI,101)
        READ  (LI,  *) MORDER,NORDER
        IJI           = 1
        GOTO 003
    012 STOP 7777
        END
```

Figure D-2. Listing of Reduced Data Approximation Program &REST9.

APPENDIX E

DATA EVALUATION PROGRAM &EVALU

As described in 5.1, program &EVALU simulates a case in which calibration data is treated as actual test data--as far as possible. From this data flow quantities of Mach number and pitch angle are derived using the whole data reduction method, and compared with the known actual values.

The program is set up to perform this comparison for all given Mach number/pitch angle combinations. However, since the process is rather extensive and time-consuming, the procedure is actually only worked out for a limited range of calibration settings.

First of all the program reads the sets of coefficients for the Mach number and pitch angle approximations (as generated in &REST8 and &REST9) into two arrays. In a loop corresponding calibration data of the "A" and "B" probes for one Mach number/pitch angle combination is read at a time. This data is read into two data arrays (ADATA(2,320) and BDATA(2,320)). For nine defined yaw angles ($\pm 65^{\circ}$, $\pm 45^{\circ}$, $\pm 30^{\circ}$, $\pm 15^{\circ}$, 0°) the program searches for given yaw angles which are closest to the defined ones and averages four yaw angles bigger and four smaller than the one found as well as it averages the corresponding pressure values. This results in nine single pairs of PA values and yaw angles. The

B probe "data acquisition" is handled differently. For a range of yaw angle smaller than the whole calibration range the output of the B probe p_B is approximated with a sixth order polynomial as a function of yaw angle. For nine specific values of yaw ($\pm 30^\circ$, $\pm 22.5^\circ$, $\pm 15^\circ$, $\pm 7.5^\circ$, 0°) corresponding pressure values p_B are calculated using the derived polynomial.

These data arrays PA(9)/YAWA(9) and PB(9)/YAWB(9) are equivalent to the data acquired in a test. They are again approximated and the pressure values PAMAX, PSA and PBMAX are calculated. The data reduction procedure as outlined in 4.5 is applied to these values and the Mach number (or X) and pitch angle are derived. Since the yaw angle is always adjusted to zero when aligned with the flow in the freejet, the yaw angle should always turn out to be zero. However, the program offers the possibility to artificially superimpose a different yaw angle in that the given relationships $p_A = P_A(\alpha)$ and $p_B = P_B(\alpha)$ are shifted to $p_A = P_A(\alpha + \Delta\alpha)$ and $p_B = P_B(\alpha + \Delta\alpha)$, where $\Delta\alpha$ is the "artificial" yaw angle. The quality of the flow quantity calculations is expressed in errors of Mach number, pitch angle and yaw angle as described in 5.1. The necessary error values are printed out and the loop is continued. Figure E-1 gives a flow chart of the program while Fig. E-2 contains a listing.

Labeled Common Block:

Common block identifier:	Variable:
DTA2	X1, Y

Variable	Type	Description
AAO	Real	Flow yaw angle derived from A probe
ABO	Real	Flow yaw angle derived from B probe
ADATA(2,320)	Real	Array to contain the A probe data
AFILE(3)	Integer	Array to contain the file name for A probe data
ASL	Real	Left hand side yaw angle of A probe output
ASR	Real	Right hand side yaw angle of A probe output
BDATA(2,320)	Real	Array to contain the B probe data
BFILE(3)	Integer	Array to contain the file name for B probe data
COEF(7)	Real	Array to contain coefficients from 2-D approximations
COEUX(7,7)	Real	Array containing the coefficients of the 3-D approximation for the velocity
COEUP(7,7)	Real	Array containing the coefficients of the 3-D approximation for the pitch angle
CPAMAX	Real	Maximum pressure coefficient A probe
CPBMAX	Real	Maximum pressure coefficient B probe
DP	Real	Pressure difference for two pressure values corresponding to two yaw angles which are separated by DX
DPX	Real	First derivative of the function $p_A(\alpha) - p_A(\alpha - \Delta\alpha)$
DX	Real	Given spread in yaw angle between PSAL and PSAR

Variable	Type	Description
ERPHI	Real	Error between measured and calculated pitch angle
ERXVEL	Real	Error between measured and calculated Mach number (Xvel rsp.)
ERYAW	Real	Error between measured and calculated yaw angle
GAMMA	Real	Pressure coefficient
ICR	Integer	Cartridge reference number
IDCB(144)	Integer	Data control block
IFILE(3)	Integer	Array containing file name
IL	Integer	Total number of words read from data file (two words for one value)
ISECU	Integer	Security code
ISIZE(2)	Integer	Array to specify file dimensions
ITYPE	Integer	Type of data file
ICLR(3)	Integer	Command to clear line above cursor
NOLF	Integer	No line feed command
NOCR	Integer	No carriage return command
PA(9)	Real	Array for A probe pressure values
PAMAX	Real	Maximum pressure of A probe
PB(9)	Real	Array for B probe pressure values
PBMAX	Real	Maximum pressure of B probe
PHI	Real	Pitch angle (calculated)
PHIME	Real	Pitch angle (measured)
PSA	Real	Static pressure equivalent of A probe
PSAL	Real	Pressure reading of A probe for a yaw angle 63^{o} to the left of the flow aligned yaw angle

Variable	Type	Description
PSAR	Real	Pressure reading of A probe for a yaw angle 63° to the right of the flow aligned yaw angle
PSTAT	Real	Static pressure
PTOTAL	Real	Total pressure
P1-P8	Real	A probe pressure values in the vicinity of a given yaw angle giving the basis to find an average pressure value for the corresponding yaw angle
XVEL	Real	Mach number equivalent dimensionless speed
XVELME	Real	Measured XVEL
X0	Real	Starting value for the iteration to find PSAL and PSAR
X1(256)	Real	Data array for 2-D approximations
Y(256)	Real	Data array for 2-D approximations
YAWA(9)	Real	Array containing A probe yaw angles
YAWB(9)	Real	Array containing B probe yaw angles
YAWOFF	Real	Superimposed yaw angle offset to simulate yaw angles different from 0°.
Y1-Y8	Real	A probe yaw angles in the vicinity of a given yaw angle equivalent to P1-P8.

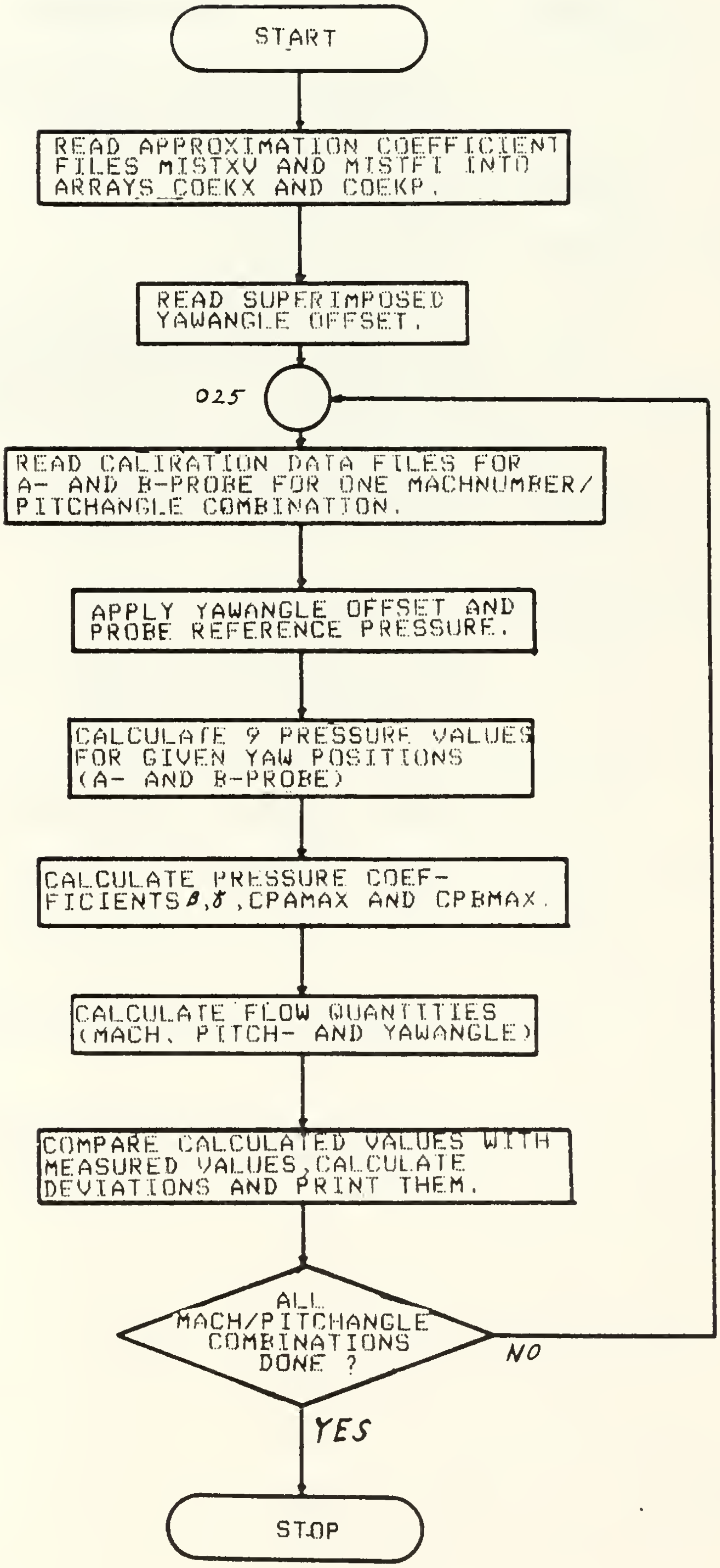


Figure E-1. Flow Chart of Data Evaluation Program &EVALU.

```
&EVALU T=00004 IS ON CR00026 USING 00051 BLKS R=0000

FTN4,L
      PROGRAM EVALU (3,99)
C     .................................................................
C     .                                                               .
C     .   THIS IS PROGRAM E V A L U (ate) !                           .
C     .                                                               .
C     .   IT CAN TREAT THE RAW DATA FROM THE A- AND B-PROBE CALI-     .
C     .   BRATION LIKE ACTUAL TEST DATA !                             .
C     .                                                               .
C     .                                                               .
C     .................................................................
      COMMON / DTA2 / X1,Y
      INTEGER IDCB(144),IFILE(3),ISIZE(2),NOLF,NOCR(2),ICLR(3)
      INTEGER AFILE(3),BFILE(3)
      REAL ADATA(2,320),BDATA(2,320),X1(256),Y(256),COEF(7)
      REAL COEKX(7,7),COEKP(7,7)
      REAL PA (9)     ,PB (9)     ,YAWA(9)   ,YAWB(9)
      DATA ISIZE (1)  /  10/
      DATA ISIZE (2)  / 128/
      DATA ITYPE      /   1/
      DATA IDCBS      / 144/
      DATA IL         /1280/
      DATA NOLF       /006537B/
      DATA NOCR       /000033B,040433B/
      DATA ICLR       /015524B,015515B,006537B/
  148 FORMAT ( " DO YOU WANT AN OUTPUT OF THE CALIBRATION COEFFICIENTS?"
     */" ENTER YES IF SO OR ANYTHING ELSE IF NOT!")
  149 FORMAT ((3A2))
  150 FORMAT (" ENTER FILE (       ) FOR X APPROXIMATION!"/
     *" DON'T FORGET SECURITY CODE & CARTRIDGE REFERENCE NUMBER!"/
     *"      :  :   "A2)
  151 FORMAT (3A2,1X,I2,1X,I2)
  152 FORMAT (//" THE DATA READ FROM FILE "3A2" ARE"/)
  153 FORMAT (" I / J   "I8,5I12)
  154 FORMAT (" "I3,7(1X,F11.6))
  155 FORMAT (" ENTER FILE (SIFP   ) FOR PHI APPROXIMATION!"/
     *" DON'T FORGET SECURITY CODE & CARTRIDGE REFERENCE NUMBER!"/
     *"SIFP  :  :   "A2)
  156 FORMAT (" ENTER THE OFFSET OF THE YAWANGLE  IN DEGREES !")
  157 FORMAT(" RESULTS FROM THE A-B SYSTEM:"//10X"CALCULATION:"15X"MEASU
     *REMENT:"12X"ERRORS"/6X"XVEL"5X"PITCH"7X"YAW"6X"XVEL"5X"PITCH"6X"XV
     *EL"5X"PITCH"7X"YAW"3X"YAW FROM A PROBE"//)
  158 FORMAT (1X(3A2))
  159 FORMAT (/" R A W  D A T A :"/"  #  A - KULITE  B - KULITE"7X"YAW A
     *"7X"YAW B")
  160 FORMAT (I3,4(2X,F10.5))
  161 FORMAT(" A-PROBE APPROXIMATION RESULTS : YAW = "3(5X,F9.2)/16X" PR
     *ESSURE (INCH H2O) = "3(3X,F11.6)/29X" CPAMAX = "F8.4/)
  162 FORMAT(/" B-PROBE APPROXIMATION RESULTS : YAW0 = "F5.1" PRESSURE
     *(INCH H2O) ="F6.2//)
  163 FORMAT (1X,F9.4,2(3X,F7.2),1X,F9.4,3X,F7.2,1X,F9.4,3(3X,F7.2))
  601 FORMAT (" I  / J "I12,6I16)
  602 FORMAT (" "I3,7(1X,F15.6))
  603 FORMAT (" ARTIFICIAL YAW ANGLE OFFSET IS : "I3"  DEGREES "//)
  604 FORMAT (/)
 1111 FORMAT (" STATEMENT # = "I3" ERROR # = "I3" ENCOUNTERED!")
      LI = LOGLU (ISESSN)
      LO = 6
      WRITE (LI,148)
      READ  (LI,149) IPRIN1
C     .................................................................
C     .                                                               .
C     .  READ FILE         FROM DISC INTO ARRAY COEKX(7,7).           .
C     .                                                               .
C     .................................................................
      WRITE (LI,150) NOLF
      READ  (LI,151)IFILE,ISECU,ICR
      WRITE (LI,149) (ICLR,I1 = 1,3)
      CALL OPEN  (IDCB,IERR,IFILE,IOPTN,ISECU,ICR,IDCBS)
      JJ = 1
      IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
      CALL READF (IDCB,IERR,COEKX,98,LEN,1)
      JJ = 2
      IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
      CALL CLOSE (IDCB,IERR,0)
      JJ = 3
      IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
      IF (IPRIN1 .NE. 2HYE) GOTO 010
```

Figure E-2. Listing of Calibration Data Evaluation Program &EVALU. (Continued on next page.)

```
C
C      ...................................................................
C      .  OUTPUT INPUT DATA.                                               .
C      .
C      ...................................................................
       WRITE (LI, 152) IFILE
       IF ( LO  .NE.  0 ) WRITE (LO, 152) IFILE
       WRITE (LI, 153) (I1,I1=1,7)
       IF ( LO  .NE.  0 ) WRITE (LO, 601) (I1,I1=1,7)
       DO 005 I1=1,7,1
       IF ( LO  .NE.  0 ) WRITE (LO, 602) I1,(COEKX(I1,J1),J1=1,7,1)
   005 WRITE (LI, 154) I1,(COEKX(I1,J1),J1=1,7,1)
C      ...................................................................
C      .                                                                   .
C      .  READ FILE        FROM DISC INTO ARRAY COEKP(7,7).                .
C      .                                                                   .
C      ...................................................................
   010 CONTINUE
       WRITE (LI,155) NOLF
       READ  (LI,151) IFILE,ISECU,ICR
       WRITE (LI,149) (ICLR,I1 = 1,3)
       CALL OPEN  (IDCB,IERR,IFILE,IOPTN,ISECU,ICR,IDCBS)
       JJ = 4
       IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
       CALL READF (IDCB,IERR,COEKP,98,LEN,1)
       JJ = 5
       IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
       CALL CLOSE (IDCB,IERR,0)
       JJ = 6
       IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
       IF (IPRIN1 .NE. 2HYE) GOTO 020
C      ...................................................................
C      .                                                                   .
C      .  OUTPUT INPUT DATA.                                               .
C      .                                                                   .
C      ...................................................................
       WRITE (LI, 152) IFILE
       IF ( LO  .NE.  0 ) WRITE (LO, 152) IFILE
       WRITE (LI, 153) (I1,I1=1,7)
       IF ( LO  .NE.  0 ) WRITE (LO, 601) (I1,I1=1,7)
       DO 015 I1=1,7,1
       IF ( LO  .NE.  0 ) WRITE (LO, 602) I1,(COEKP(I1,J1),J1=1,7,1)
   015 WRITE (LI, 154) I1,(COEKP(I1,J1),J1=1,7,1)
   020 CONTINUE
C      ...................................................................
C      .                                                                 .
C      .     THE DATA ACQUISITION SHALL BE PERFORMED NOW !                 .
C      .                                                                 .
C      .                                                                 .
C      ...................................................................
       WRITE (LI,156)
       READ  (1,   *) YAWOFF
       WRITE (LO,603) YAWOFF
       AFILE(1) = 2HA2
       AFILE(2) = 2HKP
       BFILE(1) = 2HB2
       IJI      = 1
       IS       = 1
       WRITE (LO,157)
       GOTO 135
   025 CONTINUE
       WRITE (LI,158) AFILE
       WRITE (LI,158) BFILE
       IJI      = IJI + 1
       IS       = IS  + 1
       IF (AFILE(1).EQ.2HA2.OR.AFILE(2).EQ.2HKN.OR.AFILE(3).EQ.2H25.OR.
      *AFILE(3).EQ.2H20) GOTO 135
       CALL OPEN  (IDCB,IERR,AFILE,IOPTN,ISECU,ICR,IDCBS)
       JJ = 7
       IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
       CALL READF (IDCB,IERR,ADATA,IL,LEN,1)
       JJ = 8
       IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
       CALL CLOSE (IDCB,IERR,0)
       JJ = 9
       IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR

       CALL OPEN  (IDCB,IERR,BFILE,IOPTN,ISECU,ICR,IDCBS)
       JJ = 10
       IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
```

Figure E-2. Listing of Calibration Data Evaluation Program &EVALU. (Continued on next page.)

```
      CALL READF (IDCB,IERR,BDATA,IL,LEN,1)
      JJ = 11
      IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
      CALL CLOSE (IDCB,IERR,0)
      JJ = 12
      IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR

      DO 030 I = 1,300,1
      ADATA (1,I) = ADATA (1,I) + YAWOFF
      BDATA (1,I) = BDATA (1,I) + YAWOFF
      ADATA (2,I) = ADATA (2,I) + ADATA (1,319)
  030 BDATA (2,I) = BDATA (2,I) + BDATA (1,319)
      II = 0
      DO 055 J = -60,60,15
      JI = J
      IJ = J / 2
      IF ( J .EQ. -60 ) JI = -65
      IF ( J .EQ.  60 ) JI =  65
      II = II + 1
      DO 035 I = 1,150,1
      IF (ADATA(1,I) .LT. JI ) GOTO 035
      Y1 = ADATA(1,I-2)
      P1 = ADATA(2,I-2)
      Y2 = ADATA(1,I-1)
      P2 = ADATA(2,I-1)
      Y3 = ADATA(1,I  )
      P3 = ADATA(2,I  )
      Y4 = ADATA(1,I+1)
      P4 = ADATA(2,I+1)
      GOTO 040
  035 CONTINUE
  040 DO 045 I = 151,300,1
      IF ( ADATA(1,I) .GT. JI ) GOTO 045
      Y5 = ADATA(1,I-2)
      P5 = ADATA(2,I-2)
      Y6 = ADATA(1,I-1)
      P6 = ADATA(2,I-1)
      Y7 = ADATA(1,I  )
      P7 = ADATA(2,I  )
      Y8 = ADATA(1,I+1)
      P8 = ADATA(2,I+1)
      GOTO 050
  045 CONTINUE
  050 X1(1) = Y1
      X1(2) = Y2
      X1(3) = Y3
      X1(4) = Y4
      X1(5) = Y5
      X1(6) = Y6
      X1(7) = Y7
      X1(8) = Y8
      Y (1) = P1
      Y (2) = P2
      Y (3) = P3
      Y (4) = P4
      Y (5) = P5
      Y (6) = P6
      Y (7) = P7
      Y (8) = P8
      YAWA(II) = (Y1+Y2+Y3+Y4+Y5+Y6+Y7+Y8) / 8
  055 PA  (II) = (P1+P2+P3+P4+P5+P6+P7+P8) / 8
      DO  060 I = 26,125,1
      J = I - 25
      X1(J) = BDATA(1,I)
  060 Y (J) = BDATA(2,I)
      DO 065 I = 176,275,1
      J = I - 75
      X1(J) = BDATA(1,I)
  065 Y (J) = BDATA(2,I)
      NPNTS = 200
      CALL MAT2 (NPNTS,7,COEF,-1)

      DO 070 I = 1,9,1
      YAWB(I) = 7.5 * ( I - 5 )
  070 PB  (I) = FNP(6,COEF,YAWB(I))



      WRITE (LI,159)
      DO 075 I = 1,9,1
```

Figure E-2. Listing of Calibration Data Evaluation Program &EVALU.
(Continued on next page.)

```
      079 WRITE (LI,160) I,PA(I),PB(I),YAWA(I),YAWB(I)

          PBARO  = (ADATA(2,319) + BDATA(2,319)) / 2
          PSTAT  =  PBARO * 13.585
          PTOTAL = ((ADATA(2,318) + BDATA(2,318)) / 2) + (PBARO * 13.585)
          XVELME = SQRT ( 1 - (PTOTAL/PSTAT  )**(-0.2857) )
          PHIME  = ADATA(1,320)
          DO 080 I = 1,9,1
          X1(I)     = YAWA(I)
      080 Y (I)     =  PA (I) + ( PBARO * 13.585 )
          CALL MAT2 (9,5,COEF,-4)
C         ..................................................................
C         .                                                                .
C         .  FIND MAX. OUTPUT OF A PROBE.                                  .
C         .                                                                .
C         ..................................................................
          DX      =  126.0
          X0      = -70.0
      085 DP      = (FNP(4,COEF,X0)-FNP(4,COEF,(X0+DX)))
          IF (ABS(DP) .LT. 0.0001) GOTO 090
          DPX     =-2.*COEF(3)*DX-6.*COEF(4)*X0*DX-3.*COEF(4)*DX*DX-
         *         12.*COEF(5)*X0*X0*DX-12.*COEF(5)*X0*DX*DX-4.*COEF(5)*DX**3
          X0      = X0 - DP / DPX
          GOTO 085
      090 ASL     = X0
          ASR     = X0 + DX
          AA0     = X0 + DX / 2.0
          PAMAX   = FNP(4,COEF,AA0)
          PSAL    = FNP(4,COEF,ASL)
          PSAR    = FNP(4,COEF,ASR)
          PSA     = (PSAL + PSAR) / 2.0
          PTOTAL = PAMAX
          BETA    = (PAMAX - PSA) / PAMAX
          CPAMAX = (PAMAX - PSA) / (PTOTAL - PSA)
          IF ( IPRINT .NE. 2HYE ) GOTO 095
          WRITE (LI,161) ASL,AA0,ASR,PSAL,PAMAX,PSAR,CPAMAX
          IF (LO .NE. 0 ) WRITE (LO,161) ASL,AA0,ASR,PSAL,PAMAX,PSAR,CPAMAX
      095 CONTINUE
C         ..................................................................
C         .                                                                .
C         .  APPROXIMATE B-PROBE PRESSURES.                                .
C         .                                                                .
C         ..................................................................
          DO 100  I = 1,9,1
          X1(I)       = YAWB(I)
      100 Y(I)        = PB(I) + (PBARO * 13.585)
          CALL MAT2 (9,5,COEF,-4)
          X0          = 0.00
      110 DPX         = FND(4,COEF,X0)
          IF ( ABS(DPX) .LT. 0.00001 ) GOTO 115
          X0        = X0 - DPX /(2*COEF(3) + 6*COEF(4)*X0 + 12*COEF(5)*X0*X0)
          GOTO 110
      115 AB0         = X0
          PBMAX       = FNP(4,COEF,AB0)
          IF ( IPRINT .NE. 2HYE ) GOTO 120
          WRITE (LI,162) AB0,PBMAX
          IF (LO .NE. 0 ) WRITE (LO,162) AB0,PBMAX
      120 CONTINUE
          CPBMAX      = ( PBMAX - PSA ) / ( PTOTAL - PSA )
          GAMMA       = (CPAMAX -CPBMAX) / CPAMAX
          XVEL        = 0.0
          PHI         = 0.0
          DO 125  I1 = 1,7,1
          DO 125  I2 = 1,7,1
          XVEL        = XVEL + (COEKX(I1,I2) * GAMMA**(I2-1))*BETA**(I1-1)
      125 PHI         = PHI  + (COEKX(I1,I2) * GAMMA**(I2-1))*BETA**(I1-1)
          PHI         = PHI * 180. / 3.14159
          ERXVEL      = (( XVELME - XVEL ) / XVEL ) * 100.
          ERPHI       = PHIME      - PHI
          ERYAW       = YAWOFF - AB0
          WRITE (LI,163) XVEL,PHI,AB0,XVELME,PHIME,ERXVEL,ERPHI,ERYAW,AA0
          IF(LO.NE.0)WRITE (LO,163) XVEL,PHI,AB0,XVELME,PHIME,ERXVEL,ERPHI
         * ,ERYAW,AA0
      135 CONTINUE
          IF (IS .EQ. 55 ) GOTO 500

          IF (IS .EQ. 10 ) GOTO 210
          IF (IS .EQ. 19 ) GOTO 220
          IF (IS .EQ. 28 ) GOTO 230
          IF (IS .EQ. 37 ) GOTO 240
```

Figure E-2. Listing of Calibration Data Evaluation Program &EVALU.
(Continued on next page.)

```
      IF (IS .EQ. 46 ) GOTO 250
      GOTO 260
  210 AFILE(1) = 2HA3
      BFILE(1) = 2HB3
      IJI      = IS - 9
      WRITE (LO,604)
      GOTO 260
  220 AFILE(1) = 2HA4
      BFILE(1) = 2HB4
      IJI      = IS - 18
      WRITE (LO,604)
      GOTO 260
  230 AFILE(1) = 2HA5
      BFILE(1) = 2HB5
      IJI      = IS - 27
      WRITE (LO,604)
      GOTO 260
  240 AFILE(1) = 2HA6
      BFILE(1) = 2HB6
      IJI      = IS - 36
      WRITE (LO,604)
      GOTO 260
  250 AFILE(1) = 2HA7
      BFILE(1) = 2HB7
      IJI      = IS - 45
      WRITE (LO,604)
      GOTO 260
  260 IF ( IJI .EQ. 1 ) GOTO 300
      IF ( IJI .EQ. 2 ) GOTO 310
      IF ( IJI .EQ. 3 ) GOTO 320
      IF ( IJI .EQ. 4 ) GOTO 330
      IF ( IJI .EQ. 5 ) GOTO 340
      IF ( IJI .EQ. 6 ) GOTO 350
      IF ( IJI .EQ. 7 ) GOTO 360
      IF ( IJI .EQ. 8 ) GOTO 370
      IF ( IJI .EQ. 9 ) GOTO 380
  300 AFILE(3) = 2H25
      AFILE(2) = 2HKP
      GOTO 400
  310 AFILE(3) = 2H20
      AFILE(2) = 2HKP
      GOTO 400
  320 AFILE(3) = 2H15
      AFILE(2) = 2HKP
      GOTO 400
  330 AFILE(3) = 2H10
      AFILE(2) = 2HKP
      GOTO 400
  340 AFILE(3) = 2H05
      AFILE(2) = 2HKP
      GOTO 400
  350 AFILE(3) = 2H00
      AFILE(2) = 2HKP
      GOTO 400
  360 AFILE(3) = 2H05
      AFILE(2) = 2HKN
      GOTO 400
  370 AFILE(3) = 2H10
      AFILE(2) = 2HKN
      GOTO 400
  380 AFILE(3) = 2H15
      AFILE(2) = 2HKN
      GOTO 400
  400 BFILE(2) = AFILE(2)
      BFILE(3) = AFILE(3)
      GOTO 025
  500 STOP 7777
      END
      REAL FUNCTION FNP(NORDER,COEFF,ZX)
      REAL COEFF(7)
      A1 = COEFF(NORDER+1)
      IF ( NORDER .EQ. 0 ) GOTO 02
      DO 01 I1 = 1,NORDER,1
      I = NORDER + 1 - I1
   01 A1= COEFF(I)+ZX*A1
   02 FNP = A1
      RETURN
      END
      REAL FUNCTION FND(NORDER COEFF,ZX)
      REAL COEFF(7)
      REAL COEFFD(6)
      DO 01 I=1,NORDER,1
   01 COEFFD(I) = COEFF(I+1)*I
      A1    = COEFFD(NORDER)
      NORDR= NORDER - 1
      IF( NORDR  .EQ. 0 ) GOTO 03
      DO 02 I1 = 1,NORDR,1
      I = (NORDR + 1) -I1
   02 A1 = COEFFD(I)+ZX*A1
   03 FND =A1
      RETURN
      END
```

Figure E-2. Listing of Calibration Data Evaluation Program &EVALU.

APPENDIX F

CALIBRATION TEST PROGRAM TEST

Chapter 5.2 describes the test and the test procedure used to verify the quality of the calibration in a freejet experiment. Although this experiment lacks the simulation of high frequency flow vector changes like those to be expected in its application, it seems to be the most useful check of the calibration itself and the data reduction procedure. While the set-up of the experiment and the data acquisition procedure were described in 5.2 already, details of computer program &TEST, which is used to perform the data acquisition and the data reduction, will be given herein.

Like program &EVALU, this program first reads the calibration coefficient files into two arrays. It then asks the operator to key in the barometric pressure in inches of mercury. The data acquisition itself is performed in a DO-loop, interactively with the operator. Both probes are set to nine different yaw angles and data samples are recorded. The actual pressure and yaw angle values which are used are the averages of 30 single samples each, in order to exclude any influence of some flow irregularities. Once the data is taken, the data acquisition system is released from the HP 21-MX computer control and the data reduction is started.

The nine pressure values of the A-probe are approximated with a fourth-order polynomial as a function of the yaw angle. From this approximated curve pressure values PSAL, PSAR and PAMAX are derived which are used to calculate CPAMAX and BETA. The output of the B probe is approximated the same way and the pressure PBMAX is calculated from this curve. Using PBMAX and the results of the A probe, CPBMAX and GAMMA are established. The coefficients BETA and GAMMA alone are used to derive values of Mach number (or X) and pitch angle (ϕ). The yaw angle which corresponds to the pressure value PBMAX is assumed to be the flow yaw angle. It should be close to zero since the probes are aligned with the freejet for a zero yaw angle, unless an "artificial" yaw angle has been superimposed on them as described in 5.2

The calculated values are compared to those the freejet was adjusted to. In 5.2 the results of these comparisons **were** demonstrated already.

Labeled common block:

Common block identifier:	Variable:
DTA2	X1,Y

Variable	Type	Description
AAO	Real	Flow yaw angle derived from A probe
ABO	Real	Flow yaw angle derived from B probe
AKULIT	Real	Average value of 30 A probe pressure samples

Variable	Type	Description
APRESS	Real	Single sample value of A probe pressure reading
ASL	Real	Left-hand side yaw angle of A probe output
ASR	Real	Right-hand side yaw angle of A probe output
BKULIT	Real	Average value of 30 B probe pressure samples
BPRESS	Real	Single sample value of B probe pressure reading
COEF(7)	Real	Array to contain coefficients from 2-D approximations
COEUX(7,7)	Real	Array containing the coefficients of the 3-D approximation for the velocity
COEUP(7,7)	Real	Array containing the coefficients of the 3-D approximation for the pitch angle
CPAMAX	Real	Maximum pressure coefficient A probe
CPBMAX	Real	Maximum pressure coefficient B probe
DP	Real	Pressure difference for two pressure values corresponding to two yaw angles which are separated by DX
DPX	Real	First derivative of the function $P_A(\alpha) - P_A(\alpha - \Delta\alpha)$
DX	Real	Given spread in yaw angle between PSAL and PSAR
GAMMA	Real	Pressure coefficient
ICR	Integer	Cartridge reference number
IDCB(144)	Integer	Data control block
IDCBS	Integer	Control block length (of IDCB)
IFILE(3)	Integer	Array containing file name

Variable	Type	Description
ISECU	Integer	Security code
ISIZE(2)	Integer	Array to specify file dimensions
ITYPE	Integer	Type of data file
ICLR(3)	Integer	Command to clear line above cursor
NOLF	Integer	No line feed command
PA(9)	Real	Array for A probe pressure values
PAMAX	Real	Maximum pressure of A probe
PB(9)	Real	Array for B probe pressure values
PBARO	Real	Barometric pressure inches of mercury
PBMAX	Real	Maximum pressure of B probe
PHI	Real	Pitch angle (calculated)
PSA	Real	Static pressure equivalent of A probe
PSAL	Real	Pressure reading of A probe for a yaw angle 63° to the left of the flow aligned yaw angle
PSAR	Real	Pressure reading of A probe for a yaw angle 63° to the right of the flow aligned yaw angle
PTOTAL	Real	Total pressure
XVEL	Real	Mach number equivalent dimensionless speed
X0	Real	Starting value for the iteration to find PSAL and PSAR
X1(256)	Real	Data array for 2-D approximations
Y(256)	Real	Data array for 2-D approximations
YAWANG	Real	Single sample of yaw angle reading
YAWKUL	Real	Average value of 30 yaw angle readings

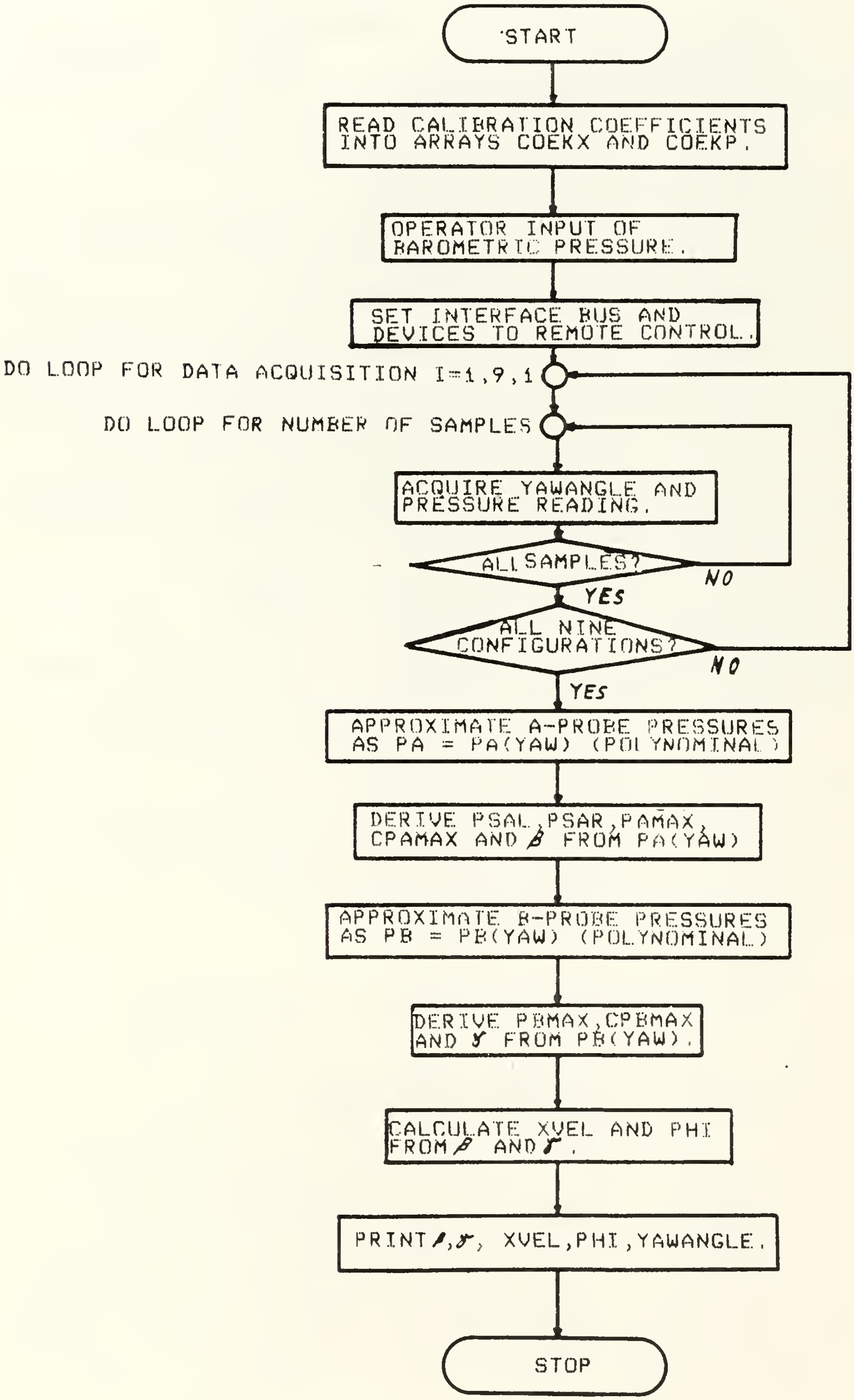


Figure F-1. Flow Chart of Calibration Evaluation Program &TEST.

```
&TEST  T=00004 IS ON CR00026 USING 00055 BLKS R=0000

FTN4,L
      PROGRAM TEST  (3,99)
C     ................................................................
C     .                                                              .
C     .      THIS IS PROGRAM TEST FOR THE A-B PROBE SYSTEM.          .
C     .                                                              .
C     .      IT ACQUIRES DATA FROM THE A-B PROBES MOUNTED IN THE FREE- .
C     .      JET IN ORDER TO CHECK THE VALIDITY OF THE CALIBRATION.  .
C     .      THE DATA IS NOT STORED, ONLY AN ONLINE OUTPUT IS AVAI-  .
C     .      LABLE.                                                  .
C     .                                                              .
C     .                                                              .
C     .                                                              .
C     ................................................................
      COMMON        / DTA2 / X1,Y
      REAL          X1(256),Y(256)
      REAL          COEF(7),COEKX(7,7),COEKP(7,7)
      REAL          PA(9),PB(9),YAW(9)
      INTEGER       IDCB(144),IFILE(3),ISIZE(2)
      INTEGER       NOLF,ICLR(3)
      DATA  IDCBS   /       144 /
      DATA  ITYPE   /         1 /
      DATA  ICLR    /015524B,015515B,006537B /
      DATA  NOLFS   /   006537B /
  101 FORMAT (" OUTPUT INPUT DATA TO ANY OTHER DEVICE?  ENTER NO
     * OR LU# !"/"  "A2)
  102 FORMAT ( " DO YOU WANT AN OUTPUT OF THE CALIBRATION COEFFICIENTS?"
     */" ENTER YES IF SO OR ANYTHING ELSE IF NOT!")
  103 FORMAT ( " DO YOU WANT AN OUTPUT OF THE CONTROLL PARAMETERS?"/" KE
     *Y YES IF SO OR ANYTHING ELSE IF NOT!")
  104 FORMAT (//" THE DATA READ FROM FILE "3A2" ARE"/)
  105 FORMAT (" I / J  "I8,5I12)
  106 FORMAT (" I  / J "I12,6I16)
  107 FORMAT (" "I3,7(1X,F15.6))
  108 FORMAT (" I  / J "I12,6I16)
  109 FORMAT (" ENTER P BARO IN INCHES HG !")
  110 FORMAT (/" R A W  D A T A :"/"  # A - KULITE  B - KULITE"9X"YAW")
  111 FORMAT (" WHEN YOU ARE READY FOR YAW ANGLE # "I2" HIT CR !")
  112 FORMAT (I3,3(2X,F10.5))
  113 FORMAT(" A-PROBE APPROXIMATION RESULTS : YAW = "3(5X,F9.2)/16X" PR
     *ESSURE (INCH H2O) = "3(3X,F11.6)/29X" CPAMAX = "F8.4/)
  114 FORMAT(/" B-PROBE APPROXIMATION RESULTS : YAW0 = "F5.1" PRESSURE
     *(INCH H2O) ="F6.2//)
  115 FORMAT(" AVERAGE VALUE RESULTS FROM THE A-B SYSTEM:"//5X"BETA"4X"G
     *AMMA"5X"Xvel"4X"Pitch"6X"Yaw"/3(F9.5),2(2X,F7.2))
  149 FORMAT ((3A2))
  150 FORMAT (I2)
 1111 FORMAT (" STATEMENT # "I4" ERROR # : "F12.2" DETECTED")
 1001 FORMAT ("F1R7M3A0H0T3")
 1501 FORMAT ("CA")
      LI = LOGLU(ISESSN)
  005 WRITE (LI, 101) NOLF
      READ  (LI, 149) IDUM
      WRITE (LI, 149) (ICLR,I1=1,2)
      IF ( IDUM  .EQ.  2HNO ) GO TO 010
      CALL CODE
      READ  (IDUM,150) LO
      IF ( LO  .EQ.   1 ) GO TO 015
      IF ( LO  .EQ.   6 ) GO TO 015
      IF ( LO  .EQ.  18 ) GO TO 015
      GO TO 005
  010 LO = 0
  015 IF ( LO  .EQ.  LI ) LO = 0
      WRITE (LI,102)
      READ  (LI,149) IPRIN1
      WRITE (LI,103)
      READ  (LI,149) IPRINT
C     ................................................................
C     .                                                              .
C     .  READ FILE SIFX22 FROM DISC INTO ARRAY COEKX(7,7).           .
C     .                                                              .
C     ................................................................
      IFILE(1) = 2HSI
      IFILE(2) = 2HFX
      IFILE(3) = 2H43
      ISECU    = 00
      ICR      = 26
      CALL OPEN  (IDCB,IERR,IFILE,IOPTN,ISECU,ICR,IDCBS)
```

Figure F-2. Listing of Program to Test the Quality of the Calibration: &TEST. (Continued on next page.)

```
      JJ = 1
      IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
      CALL READF (IDCB,IERR,COEKX,98,LEN,1)
      JJ = 2
      IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
      CALL CLOSE (IDCB,IERR,0)
      JJ = 3
      IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
      IF (IPRIN1 .NE. 2HYE) GOTO 025
C     ...............................................................
C     .                                                             .
C     .  OUTPUT INPUT DATA.                                         .
C     .                                                             .
C     ...............................................................
      WRITE (LI,104) IFILE
      IF ( LO  .NE.  0 ) WRITE (LO,104) IFILE
      WRITE (LI,105) (I1,I1=1,7)
      IF ( LO  .NE.  0 ) WRITE (LO,106) (I1,I1=1,7)
      DO 020 I1=1,7,1
      IF ( LO  .NE.  0 ) WRITE (LO,107) I1,(COEKX(I1,J1),J1=1,7,1)
  020 WRITE (LI,108) I1,(COEKX(I1,J1),J1=1,7,1)
C     ...............................................................
C     .                                                             .
C     .  READ FILE SIFP22 FROM DISC INTO ARRAY COEKP(7,7).          .
C     .                                                             .
C     ...............................................................
  025 IFILE(1) = 2HSI
      IFILE(2) = 2HFP
      IFILE(3) = 2H43
      CALL OPEN  (IDCB,IERR,IFILE,IOPTN,ISECU,ICR,IDCBS)
      JJ = 4
      IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
      CALL READF (IDCB,IERR,COEKP,98,LEN,1)
      JJ = 5
      IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
      CALL CLOSE (IDCB,IERR,0)
      JJ = 6
      IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
      IF (IPRIN1 .NE. 2HYE) GOTO 035
C     ...............................................................
C     .                                                             .
C     .  OUTPUT INPUT DATA.                                         .
C     .                                                             .
C     ...............................................................
      WRITE (LI,104) IFILE
      IF ( LO  .NE.  0 ) WRITE (LO,104) IFILE
      WRITE (LI,105) (I1,I1=1,7)
      IF ( LO  .NE.  0 ) WRITE (LO,106) (I1,I1=1,7)
      DO 030 I1=1,7,1
      IF ( LO  .NE.  0 ) WRITE (LO,107) I1,(COEKP(I1,J1),J1=1,7,1)
  030 WRITE (LI,108) I1,(COEKP(I1,J1),J1=1,7,1)
  035 CONTINUE
C     ...............................................................
C     .                                                             .
C     .     THE DATA ACQUISITION SHALL BE PERFORMED NOW !           .
C     .                                                             .
C     .                                                             .
C     ...............................................................
      WRITE (LI,109)
      READ  (LI,  *) PBARO
      CALL  ABRT  (7,2)
      CALL  RMOTE ( 10)
      CALL  RMOTE ( 15)

      WRITE (10,1001)
      WRITE (15,1501)

      WRITE (LO,110)
      DO 050 I = 1,9,1
  040 WRITE (LI,111) I
      READ  (LI,149) IDUM
      IF ( IDUM .NE. 2H  ) GOTO 040
      AKULIT   = 0.0
      YAWKUL   = 0.0
      BKULIT   = 0.0
      DO 045 J = 1,30,1
      YAWANG   = SCANR (15,22,01)
      BPRESS   = SCANR (15,23,01)
      APRESS   = SCANR (15,24,01)
      AKULIT   = AKULIT + APRESS
```

Figure F-2. Listing of Program to Test the Quality of the Calibration: &TI
(Continued on next page.)

```
      YAWKUL    = YAWKUL + YAWANG
  045 BKULIT    = BKULIT + BPRESS
      PA (I)    = AKULIT / 30
      PB (I)    = BKULIT / 30
      YAW(I)    = YAWKUL / 30
  050 WRITE (LO,112) I,PA(I),PB(I),YAW(I)
      CALL  CLEAR  (7,1)
      CALL  LOCL   (  7)

C     .............................................................
C     .                                                           .
C     .   START DATA REDUCTION.                                   .
C     .                                                           .
C     .............................................................
      DO 055 I = 1,9,1
      X1(I)      = YAW (I) * 10000
  055 Y (I)      = (PA (I) * 10000 ) + ( PBARO * 13.585 )
      CALL MAT2 (9,5,COEF,-4)
C     ...............................................................
C     .                                                             .
C     .  FIND MAX. OUTPUT OF A PROBE.                               .
C     .                                                             .
C     ...............................................................
      DX         =  126.0
      X0         =  -70.0
  060 DP         = (FNP(4,COEF,X0) - FNP(4,COEF,(X0+DX)))
      IF (ABS(DP) .LT. 0.0001 ) GOTO 065
      DPX        = -2.0*COEF(3)*DX-6.0*COEF(4)*X0*DX-3.0*COEF(4)*DX*DX-
     *       12.0*COEF(5)*X0*X0*DX-12*COEF(5)*X0*DX*DX-4.0*COEF(5)*DX**3
      X0         = X0 - DP / DPX
      GOTO 060
  065 ASL        = X0
      ASR        = X0 + DX
      AA0        = X0 + DX / 2.0
      PAMAX      = FNP(4,COEF,AA0)
      PSAL       = FNP(4,COEF,ASL)
      PSAR       = FNP(4,COEF,ASR)
      PSA        = (PSAL + PSAR ) / 2.0
      PTOTAL     = PAMAX
      BETA       = (PAMAX - PSA ) / PAMAX
      CPAMAX     = (PAMAX - PSA ) / ( PTOTAL - PSA )
      IF ( IPRINT .NE. 2HYE ) GOTO 070
      WRITE (LI,113) ASL,AA0,ASR,PSAL,PAMAX,PSAR,CPAMAX
      IF (LO .NE. 0 ) WRITE (LO,113) ASL,AA0,ASR,PSAL,PAMAX,PSAR,CPAMAX
  070 CONTINUE
C     ..............................................................
C     .                                                            .
C     .   APPROXIMATE B PROBE PRESSURES.                           .
C     .                                                            .
C     ..............................................................
      DO 075 I = 1,9,1
      X1(I)      = YAW (I) * 10000
  075 Y (I)      = (PB (I) * 10000 ) + ( PBARO * 13.585 )
      CALL MAT2 (9,5,COEF,-4)
      X0         =  0.00
  080 DPX        = FND(4,COEF,X0)
      IF ( ABS(DPX) .LT. 0.00001 ) GOTO 085
      X0         = X0 - DPX /(2*COEF(3) + 6*COEF(4)*X0 + 12*COEF(5)*X0*X0)
      GOTO 080
  085 AB0        = X0
      PBMAX      = FNP(4,COEF,AB0)
      IF ( IPRINT .NE. 2HYE ) GOTO 090
      WRITE (LI,114) AB0,PBMAX
      IF ( LO .NE. 0 ) WRITE (LO,114) AB0,PBMAX
  090 CONTINUE
      CPBMAX     = ( PBMAX - PSA ) / (PTOTAL - PSA )
      GAMMA      = (CPAMAX - CPBMAX ) / CPAMAX
      XVEL       = 0.0
      PHI        = 0.0
      DO 095 I1= 1,7,1
      DO 095 I2= 1,7,1
      XVEL       = XVEL + (COEKX(I1,I2) *GAMMA**(I2-1))*BETA **(I1-1)
  095 PHI        = PHI  + (COEKP(I1,I2) *GAMMA**(I2-1))*BETA **(I1-1)
      PHI        = PHI * 180 / 3.14159
      WRITE (LI,115) BETA,GAMMA,XVEL,PHI,AB0
      IF(LO .NE. 0) WRITE (LO,115) BETA,GAMMA,XVEL,PHI,AB0
      STOP 7777
      END
      REAL FUNCTION FNP(NORDER,COEFF,ZX)
      REAL COEFF(7)
```

ure F-2. Listing of Program to Test the Quality of the Calibration: &TEST. (Continued on next page.)

```
          A1 = COEFF(NORDER+1)
          IF ( NORDER .EQ. 0 ) GOTO 02
          DO 01 I1 = 1,NORDER,1
          I = NORDER + 1 - I1
      01  A1= COEFF(I)+ZX*A1
      02  FNP = A1
          RETURN
          END
          REAL FUNCTION FND(NORDER,COEFF,ZX)
          REAL COEFF (7)
          REAL COEFFD(6)
          DO 01 I=1,NORDER,1
      01  COEFFD(I) = COEFF(I+1)*I
          A1    = COEFFD(NORDER)
          NORDR= NORDER - 1
          IF( NORDR  .EQ. 0 ) GOTO 03
          DO 02 I1 = 1,NORDR,1
          I = (NORDR + 1) -I1
      02  A1 = COEFFD(I)+ZX*A1
      03  FND =A1
          RETURN
          END
          REAL FUNCTION SCANR (LU,ICHAN,K)
    C     ...............................................................
    C     .                                                             .
    C     .  Close relay ICHAN on scanner LU and read the instrument    .
    C     .  indicated by K.                                            .
    C     .  Author:    Robert N. Geopfarth                             .
    C     .  Date:      February 31, 1979                               .
    C     .  Detailed program description is available in TXCO log;  the .
    C     .  variables are:                                             .
    C     .  LU      ...   LU# of desired scanner (8 or 15).            .
    C     .  ICHAN   ...   Scanner channel (integer).                   .
    C     .  IC      ...   Scanner channel (ASCII).                     .
    C     .  K       ...   Instrument code ( DVM = 1 / Counter = 2 ).   .
    C     .                                                             .
    C     ...............................................................
         *, Closes scanner and reads DVM, counter. "
     101 FORMAT (A2)
     801 FORMAT ("C")
    1001 FORMAT ("T3T3")
    1201 FORMAT ("T")
    1501 FORMAT ("C")

         WRITE ( 8, 801)
         WRITE (15,1501)
         IC = ICON(ICHAN,0)
         WRITE (LU, 101) IC
         GO TO (01,02) K

      01 CALL TRIGR (10)
         READ  (10,   *) DUM
         CALL TRIGR (10)
         READ  (10,   *) SCANR
         GO TO 03

      02 WRITE (12,1201)
         READ  (12,   *) SCANR

      03 WRITE (LU, 801)
         RETURN
         END
         INTEGER FUNCTION ICON(I,N)
         IC=I+N
         IF(IC.LT.10) GO TO 100
         CALL CODE
         WRITE(ICON,60)IC
    60   FORMAT(I2)
         RETURN
    100  ICON=IC+30060B
         RETURN
         END
```

Figure F-2. Listing of Program to Test the Quality of the Calibration: &T

APPENDIX G

CALIBRATION DATA (C_{PoB}) APPROXIMATION PROGRAM &RES10

As shown in Fig. 19, CPBO is well behaved as a function of pitch angle and Mach number as well. Thus it is approximated as a function of these two variables. Program &RES10 handles this procedure. It is in principal again the same program as &REST8, like &REST9, so that a detailed program description will not be given here. However, it shall be mentioned here that the data which is the basis of the approximation is contained in data file ABNEW2. This is an indication that this file contains all the data necessary to represent the whole calibration.

For the evaluation of the quality of the approximation, errors are printed out as were for &REST8. These are calculated as:

$$\varepsilon_{C_{P_{B0}}} = \frac{C_{P_{B_{0m}}} - C_{P_{B_{0c}}}}{C_{P_{B_{0m}}}} \cdot 100$$

index m = known from measurement
index c = calculated

The variation in the order of polynomials for the approximation was changed in two DO-loops also and the one for the best error results chosen. Those coefficients are stored in file MISTCP on cartridge 26. Figure G-1 shows the coefficients and the associated errors. The highlighted area gives the range of Mach number and pitch angle which will most likely occur. Thus the error distribution within there is most important.

Figure G-2 gives a listing of program &RES10. The similarities to programs &REST8 and &REST9 are obvious, so that no flow chart or further explanations are given.

COEFFICIENTS FOR THE CALIBRATION SURFACE STORED IN FILE [illegible]

Morder ↓ / Norder →	1	2	3	4
1	.504279	2.676250	-9.602358	14.6[illegible]
2	-1.369715	1.062078	-2.308957	12.6[illegible]405
3	-1.138980	-4.491507	25.229003	-45.602787
4	1.332497	7.475204	-31.004311	53.495729
	1	2	3	4

ERRORS AT EACH POINT

Mach Number	Pitch Angle → 25° 1	2	3	4	5	6	7	8	-15° 9
0.2 1	26.031	3.390	-2.575	-.974	.674	1.031	.045	-1.310	.871
2	-12.991	2.620	-.805	-.073	-.216	.406	.157	.106	-.235
3	.104	2.414	1.[illegible]	.6[illegible]	-.6[illegible]	-1.104	.355	.525	.259
4	-.319	.255	-.734	-.476	-.264	-.531	.127	.708	-.049
5	-.104	.124	-1.169	1.115	.624	.742	-.199	-.966	-.305
0.7 6	1.858	-1.242	-.760	.974	.494	-.012	-.231	-.379	.627
	1	2	3	4	5	6	7	8	9

Table G-I. Coefficients and errors for C_{PoB} approximation depending on X_{vel} and ϕ.

```
- &RES10 T=00004 IS ON CR00026 USING 00024 BLKS R=0000

FTN4,L
      PROGRAM RES10 (3,99)
C     ..................................................................
C     . This is program RES(tore) 10.                                    .
C     .                                                                  .
C     . There are some programs REST , which in principle do all the     .
C     . same : They restore calibration data of a probe into a form      .
C     . that can be used to approximate this data by a calibration       .
C     . surface.                                                         .
C     . The software used for the surface approximation is available     .
C     . in the Turbopropulsion Laboratory Binary Library(TPLBL).         .
C     . See NPS67-80-001CR for further reference.                        .
C     . In this particular case the calibration data of the              .
C     .                                                                  .
C     .  N E W   A -   A N D   B - P R O B E S                           .
C     .                                                                  .
C     .  are approximated !                                              .
C     .  CpOB   =   f(PHI,XVEL)                                          .
C     .                                                                  .
C     ..................................................................
      COMMON / MATRX / A,B
      COMMON / SUMME / PHI,XVEL,CPOB
      REAL PLOTR(256),A(49,49),B(49),COEFF(7,7),D(10,54)
      INTEGER IDCB(144),IFILE(3),ISIZE(2),NOCR(2),ICLR(3)
      REAL XVEL(16,16),PHI(16,16),CPOB(16,16),R(16)
      DATA PI /3.141593/
      DATA IFILE /2HAB,2HNE,2HW2/
      DATA NOCR /000033B,040433B/
      DATA ICLR /015524B,015515B,006537B/
      DATA ISECU /0/
      DATA ICR    /26/
      DATA ITYPE /1/
      DATA ISIZE /3,128/
      DATA IDCBS /144/
  101 FORMAT (" SELECT SET OF COEFFICIENTS FOR BEST RESULTS !"/" ENTER M
     *ORDER AND NORDER NOW :")
  149 FORMAT(""((3A2)))
  601 FORMAT (///" COEFFICIENTS FOR THE CALIBRATION SURFACE STORED IN FI
     *LE :"3A2/)
  602 FORMAT ((3X,16(6X,I2)))
  603 FORMAT (1X,I2,16(1X,F7.3)/3(3X,16(1X,F7.3)/))
  604 FORMAT (///" ERRORS AT EACH POINT (%)"/)
  605 FORMAT ((3X,10(11X,I2)))
  606 FORMAT (1X,I2,7(2X,F11.6))
 1111 FORMAT ( " STATEMENT # "I4 " ERROR # "I4 " ENCOUNTERED !")
      LI = LOGLU(I)
C     ..................................................................
C     .                                                                  .
C     .  READ DATA FILE ABNEW .                                          .
C     .                                                                  .
C     ..................................................................
      CALL OPEN (IDCB,IERR,IFILE,IOPTN,ISECU,ICR,IDCBS)
      JJ = 1
      IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
      CALL READF (IDCB,IERR,D,1080,LEN,1)
      JJ = 2
      IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
      CALL CLOSE (IDCB,IERR,0)
      JJ = 3
      IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
      IJ          = 0
      DO 005  I   = 1,6,1
      DO 005  J   = 1,9,1
      IJ          = IJ + 1
      XVEL (I,J)  = D(3,IJ)
      IF ( J .EQ. 6 ) D(4,IJ) = D(4,IJ) + 0.00001
      PHI  (I,J)  = D(4,IJ) * PI / 180
  005 CPOB (I,J)  = D(6,IJ)
      NMACH  = 6
      NPITCH = 9
  010 CONTINUE


C     ..................................................................
C     .
C        CALCULATE CALIBRATION SURFACE COEFFICIENTS
C
```

Figure G-1. Listing of Program to Approximation C_{PoB} Values: &RES10. (Continued on next page.)

```
      IJI = 0
      DO  060 MU = 1,6,1
      DO  060 NU = 1,6,1
      MORDER     = MU
      NORDER     = NU
  015 CONTINUE
      DO 020 I   = 1,7,1
      DO 020 J   = 1,7,1
  020 COEFF(I,J) = 0.0
      M=MORDER+1
      N=NORDER+1
      CALL COMAT (A,B,M,N,NMACH,NPITCH)
      NEQUS=M*N
      CALL ELGJ (NEQUS)
      I1=0
      DO 025  I = 1,M,1
      DO 025  J = 1,N,1
      I1        = I1+1
  025 COEFF(I,J)= B(I1)
      IF ( IJI .NE. 1 ) GOTO 030
      IFILE(1) = 2HMI
      IFILE(2) = 2HST
      IFILE(3) = 2HCP
      CALL CREAT (IDCB,IERR,IFILE,ISIZE,ITYPE,ISECU,ICR,IDCBS)
      JJ = 4
      IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
      CALL OPEN  (IDCB,IERR,IFILE,IOPTN,ISECU,ICR,IDCBS)
      JJ = 5
      IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
      CALL WRITF (IDCB,IERR,COEFF,98)
      JJ = 6
      IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
      CALL CLOSE (IDCB,IERR,0)
      JJ = 7
      IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
      WRITE (6,601) IFILE
  030 CONTINUE
      WRITE (6,605) (J,J=1,N,1)
      DO 035  I = 1,M,1
  035 WRITE (6,606) I,(COEFF(I,J),J=1,N,1)
      WRITE (6,605) (J,J=1,N,1)



C     ..................................................................
C     .                                                                .
C     .  OVERWRITE DATA ARRAY WITH CALCULATED DATA                     .
C     .                                                                .
C     ..................................................................
      WRITE (6,604)
      WRITE (6,602) (J,J=1,NPITCH,1)
      DO 050  I = 1,NMACH,1
      DO 045  J = 1,NPITCH,1
      SUM       = 0.
      DO 040  I1 = 1,M,1
      DO 040  J1 = 1,N,1
  040 SUM=SUM+(COEFF(I1,J1)*XVEL(I,J)**(J1-1))*PHI  (I,J)**(I1-1)
  045 R(J)=((CPOB(I,J)-SUM)/CPOB(I,J))*100
  050 WRITE (6,603) I,(R(J),J=1,NPITCH,1)
      WRITE (6,602) (J,J=1,NPITCH,1)

      IF (IJI .EQ. 1 ) GOTO 065

  060 CONTINUE
      WRITE (LI,101)
      READ  (LI,  *) MORDER,NORDER
      IJI = 1
      GOTO 015
  065 STOP 7777
      END
```

Figure G-1. Listing of Program to Approximation C_{PoB} Values: &RES10.

APPENDIX H

TEST DATA ACQUISITION PROGRAM &ABKUL

Program &ABKUL is rather complex. The amount of data gathered and stored is quite extensive. Since the data reduction procedure is faster if only one file contains all data, the use of a single data file seems to be justified.

Before any data acquisition is performed, the file to contain the data is created under a name given by the operator. This way it is ensured that there is sufficient space on the cartridge to store the file. Once this is done, the data array (DATA(20,256)) is preset with zeros and the interface bus and devices are set to remote control. The first part of the data acquisition is for the first on-line calibration. Both Kulite probes are at the same radius as the rotor exit combination probe and all probe yaw angles are fixed to the same angle given by the combination probe. This one is assumed to be the time averaged flow yaw angle. The reference pressure on the back side of the Kulite transducers is changed to a known value and a set of data is recorded. This data includes the pressure readings of the Kulite probes and their reference pressure as well as all the information available from the combination probe. Once this data is collected, the Kulite probe reference pressure is changed to another value and another set of data is acquired. This procedure is carried out for a total of four different reference pressures, allowing sufficient time after each pressure change for the measuring system to adapt to the new pressure. After the last pressure is applied, the reference pressure is reset to barometric pressure and the data acquisition for the first on-line calibration is completed. During the data acquisition the recorded data is printed out immediately so that its quality can be evaluated right away.

Before the acquisition of high speed data is performed, the operator is asked to specify the number of yaw angles he wants the Kulite probes to be moved to. A maximum of nine is possible and this number should always be favored to ensure sufficient data to cover a range of 160° in yaw angle as explained in 6.3. The program asks the operator to set both Kulite probes to the first yaw angle and to initiate the data acquisition. In a first DO-loop data from the type A probe is gathered for 256 consecutive circumferential positions. Each of the 256 values is the average of 40 single samples which are acquired on consecutive revolutions. In a second DO-loop the same kind of data is acquired from the B probe. Since the two probes are mounted on the compressor case wall separated by 270° circumferentially, the trigger numbers where the data acquisition starts are separated by a number of 1728 cts.=270° for the two probes. (The trigger device splits 360° up into 2304 single counts. Both probes acquire data for 256 counts, 40° respectively. Since the rotor has 18 blades, two blade passages are covered.)

When the second DO-loop is done, steady state data from the combination probe and the Kulite probes is acquired. This data is of the same kind as that for the on-line calibration data and is in general very helpful for checking purposes. It is printed out as soon as it is acquired. From the high speed data the overall average values for all 256 positions from A and B probes are derived and printed out also.

The DO-loop is continued by the operator initializing the acquisition for another yaw angle setting of both probes.

When the data for all desired yaw positions is acquired, a second on-line calibration is performed. The results are printed out immediately so that they can be compared to those from the first calibration and obvious errors can be detected right away. From the two on-line calibrations slopes and intercepts are derived for both probes as described in 6.3.

Finally the data is stored in the assigned file.

Figure H-1 gives a flow chart of program &ABKUL, while Fig. H-2 is a listing.

Variables	Type	Description
AVRGA	Real	Average value of A probe output
AVRGB	Real	Average value of B probe output
BUFR(1664)	Integer	Buffer array
DATA(20,256)	Real	Data array
DCA	Real	DC-level reading of A probe
DCB	Real	DC-level reading of B probe

Variables	Type	Description
DE	Real	Voltage difference between combination probe and reference temperature probe thermocouple
E	Real	Voltage reading of combination probe thermocouple
FSVLTG	Real	Calibration factor Kulite probe reading
IBUFF(99)	Integer	Array for Kulite sample values
IBLADE	Integer	Number of compressor rotor blade pairs to be investigated
ICLR(3)	Integer	Command to clear line above the cursor
ICOUNT	Integer	Number of acquired data points (1 through 256)
ICR	Integer	Cartridge reference number
IDCB(144)	Integer	Data control block
IDCBS	Integer	Data control block length
IDUM	Integer	Dummy variable
IFILE(3)	Integer	Array containing file name
IL	Integer	Total number of words stored in data file (two words for one value)
ISECU	Integer	Security code
IRPM	Integer	Rotational speed derived from triggered measurements
ISIZE(2)	Integer	Array to specify fill dimensions
ITYPE	Integer	Type of data file
LI	Integer	Input device number
LO	Integer	Output device number
MASK	Integer	Masking variable
NOLF	Integer	No line feed command

Variables	Type	Description
PBARO	Real	Barometric pressure
PCAL	Real	Calibration pressure for the Scanivalve
PREF	Real	Reference pressure for the Kulite probes
P1, P23, P4	Real	Pressure readings for the combination probe
RPM	Real	Compressor speed as read from counter
SECON	Real	Intercept of either A or B probe calibration
SLOPE	Real	Slope of either A or B probe calibration
TARE	Real	"Zero drift" for Scanivalve transducer
X(4)	Real	Array for on-line calibration data
XIMA	Real	Immersion of A probe
XIMB	Real	Immersion of B probe
XIMC	Real	Immersion of combination probe
Y(4)	Real	Array for on-line calibration data
YAWA	Real	Yaw angle of A probe
YAWB	Real	Yaw angle of B probe
YAWC	Real	Yaw angle of C probe
YAWP	Real	Total number of yaw positions for the A and B probe

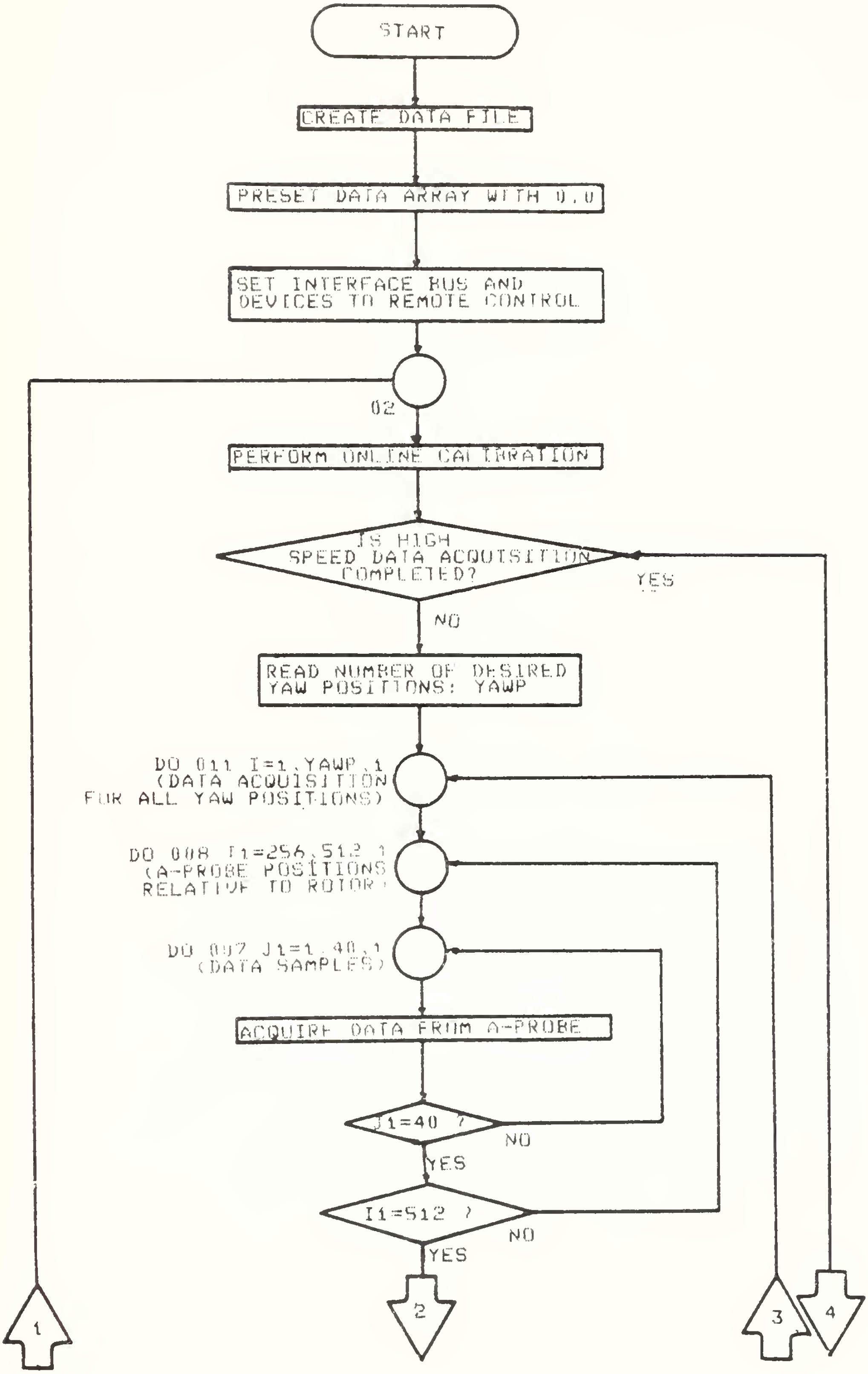


Figure H-1. Flow Chart of Data Acquisition Program &ABKUL. (Continued on next page.)

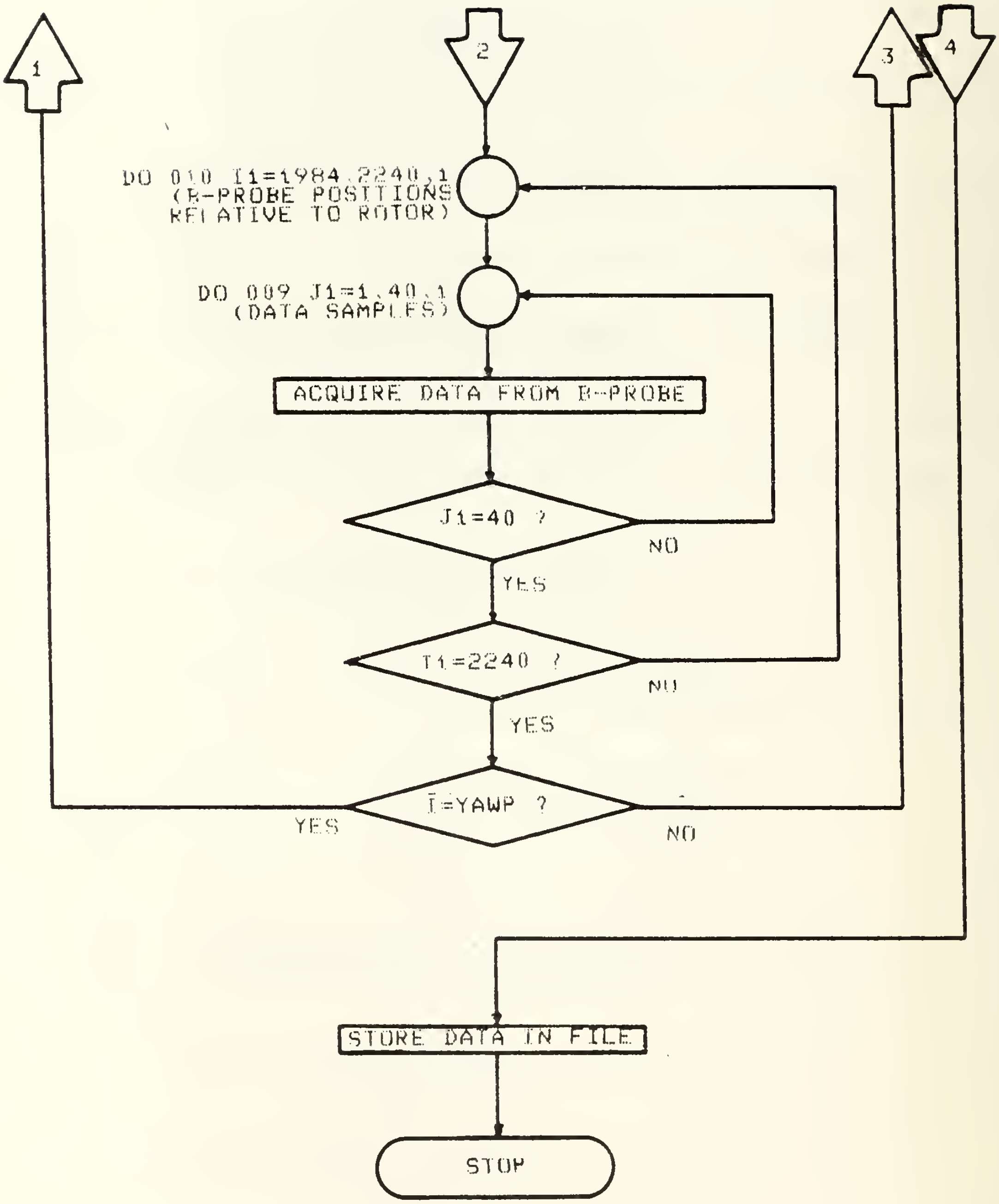


Figure H-1. Flow Chart of Data Acquisition Program &ABKUL.
(Continued on next page.)

```
&ABKUL T=00004 IS ON CR00026 USING 00061 BLKS R=0000

FTN4,L
      PROGRAM ABKUL (3,99)
C     ..................................................................
C     .                                                                .
C     .    This is program ABKUL(ite).                                 .
C     .    It performs an online calibration of the A and B kuliteprobes .
C     .    and a data acquasition for 7 yaw positions of these probes as .
C     .    well.                                                       .
C     .                                                                .
C     .    Author :  Friedrich Neuhoff                                 .
C     .    Date   :  July 28, 1981                                     .
C     .                                                                .
C     ..................................................................
C     ******************************************************************
C     *                                                                *
C     *    NOTE : IF THE "C" WILL BE REMOVED FROM THE STATEMENTS       *
C     *           CONTAINING ASTERISKS IN COLUMN 73 AND HIGHER,        *
C     *           NO STEADY STATE DATA WILL BE ACCUIRED AND ONLY       *
C     *           ONE SET OF HIGH SPEED DATA WILL BE TAKEN!            *
C     *                                                                *
C     ******************************************************************
      DIMENSION IBUFF(99),IGCB(192)
      REAL    DATA(20,256),X(4),Y(4),AVRGA,AVRGB
      INTEGER BUFR (1664)
      INTEGER NOLF,IDCB(144),ICLR(3),IFILE(3),ISIZE(2)
      DATA  IDCBS    /  144/
      DATA  ISECU    /   00/
      DATA  ICR      /   28/
      DATA  ITYPE    /    1/
      DATA  IL       /10240/
      DATA  ISIZE(1) /   80/
      DATA  ISIZE(2) /  128/
      DATA  NOLF     / 006537B/
      DATA  ICLR     / 015524B,015515B,006537B/
      DATA  MASK     / 177700B/
      DATA  FSVLTG   / .1E01/
  101 FORMAT (" This is program ABKUL(ite)."/" It first performs a data
     *acquasition for an online calibration of the A and B "/" probes."/
     *" Then it takes paced data from the probes at 7 different yaw posi
     *tions "/" interactively with the operator. At the end another set
     *of data for an online"/" calibration is accquired!"//" The whole r
     *aw data is stored in one file!")
  102 FORMAT (////" The online calibration shall be performed now!"/" It
     * allows four different reference pressures!"//" When the first ref
     *.pressure is applied correctly, key GO!")
  103 FORMAT(///,36X" Online calibration"///)
  104 FORMAT(13X"Immer.comb.   yaw comb."10X"P1"9X"P23"10X"P4"/5X"Point
     *# Immer.A pr.   yaw A pr."9X"DCA"8X"Pref"10X"Tt"/13X"Immer.B pr.
     * yaw B pr."9X"DCB"9X"RPM"9X"DTt"///)
  105 FORMAT (/12X,5(2X,F10.6)/5X,I2,5X,5(2X,F10.6)/12X,5(2X,F10.6))
  106 FORMAT (" Apply the next ref. press. and key GO when the condition
     *s are stable"/"enough for the next reading!")
  107 FORMAT(" 1st online calibration done!"/" Reset the ref. press. for
     * the high speed data acquasition!"/" Enter the number of different
     * yaw angles you want."/ " Hit CR after that to continue!")
  108 FORMAT(///36X"Average values from paced run"///)
  109 FORMAT (" Adjust both kulite probes to yaw angle number:"I2/" Key
     *GO when this is done!")
  110 FORMAT(/24X"A probe"30X"B probe"/26X"Slope"6X"Intercept * "10X"Slo
     *pe"6X"Intercept"/47X"*"/" 1st calibration"2(3X,F12.6)" * "2(3X,F12
     *.6)/47X"*"/" 2nd calibration"2(3X,F12.6)" * "2(3X,F12.6))
  111 FORMAT (" Second online calibration done!"/" Reset the ref. press.
     * and consider the data acquasition to be completed!"//" Compare th
     *e results of the two online calibrations and check for drift!"/" I
     *f the drift can be accepted, key in the file name you want the dat
     *a"/" to be stored in!")
  112 FORMAT (" Averaged values paced output : A probe :"F10.5" B probe
     *:"F10.5)
  148 FORMAT (" Output input data to any other device?  Enter NO
     * or LU# !"/"  "A2)
  149 FORMAT ((3A2))
  150 FORMAT (I2)
  801 FORMAT ("CA")
 1001 FORMAT ("F1R7M3A1H0T3")
 1201 FORMAT ("PF4G6T")
 1501 FORMAT ("CA")

 1111 FORMAT (" STATEMENT # "I5" ERROR # "I7"ENCOUNTERED!")
```

Figure H-2. Listing of Data Acquisition Program &ABKUL.
(Continued on next page.)

```
      LI = LOGLU(ISESSN)
   77 WRITE (LI, 148) NOLF
      READ  (LI, 149) IDUM
      WRITE (LI, 149) (ICLR,I1=1,2)
      IF ( IDUM  .EQ.  2HNO ) GO TO 78
      CALL CODE
      READ  (IDUM,150) LO
      IF ( LO  .EQ.   1 ) GO TO 79
      IF ( LO  .EQ.   6 ) GO TO 79
      IF ( LO  .EQ.  18 ) GO TO 79
      GO TO 77
   78 LO = 0
   79 IF ( LO  .EQ.  LI ) LO = 0
      WRITE (LI,101)

C     ....................................................................
C     .                                                                  .
C     .    Preset data array with zeros!                                 .
C     .                                                                  .
C     ....................................................................
      DO  01  I = 1, 20,1
      DO  01  J = 1,256,1
   01 DATA (I,J) = 0.0
C     ......................................................................
C     .                                                                    .
C     .    Set interface bus and devices to remote control !               .
C     .                                                                    .
C     ......................................................................
      CALL  ABRT(7,2)
      CALL  RMOTE( 8)
      CALL  RMOTE(10)
      CALL  RMOTE(12)
      CALL  RMOTE(15)
      WRITE ( 8, 801)
      WRITE (10,1001)
      WRITE (12,1201)
      WRITE (15,1501)
C     ....................................................................
C     .                                                                  .
C     .  Perform the data acquasition for the first online calibration .
C     .                                                                  .
C     ....................................................................
      J = 1
C     GOTO 05
   02 I = 1
      WRITE (LI,102)
      READ  (LI,149) IDUM
      IF ( IDUM .NE. 2HGO ) GOTO 02
      WRITE (LI,103)
      IF ( LO .NE. 0 ) WRITE (LO,103)
      WRITE (LI,104)
      IF (LO .NE. 0 ) WRITE (LO,104)
   03 TARE2  =  ACQN ( 4, 1,10)
      PCAL   =  ACQN ( 4, 2,10)
      P1     =  ACQN ( 4, 6,10)
      P23    =  ACQN ( 4, 7,10)
      P4     =  ACQN ( 4, 8,10)
      RPM    =  SCANR( 8,17, 2)
      PBARO  =  SCANR( 8,25, 1)
      XIMC   =  SCANR( 8,32, 1)
      YAWC   =  SCANR( 8,33, 1)
      XIMA   =  SCANR( 8,34, 1)
      YAWA   =  SCANR( 8,35, 1)
      XIMB   =  SCANR( 8,36, 1)
      YAWB   =  SCANR( 8,37, 1)
      PREF   =  SCANR( 8,39, 1)
      E      =  SCANR(15,18, 1)
      DE     =  SCANR(15,19, 1)
      DCA    =  SCANR(15,52, 1)
      DCB    =  SCANR(15,53, 1)
      DATA(1,J   )  = TARE2
      DATA(1,J+ 1)  = PCAL2
      DATA(1,J+ 2)  = P1
      DATA(1,J+ 3)  = P23
      DATA(1,J+ 4)  = P4
      DATA(1,J+ 5)  = RPM
      DATA(1,J+ 6)  = PBARO
      DATA(1,J+ 7)  = XIMC
      DATA(1,J+ 8)  = YAWC
      DATA(1,J+ 9)  = XIMA
```

Figure H-2. Listing of Data Acquisition Program &ABKUL.
(Continued on next page.)

```
      DATA(1,J+10)  = YAWA
      DATA(1,J+11)  = XIMB
      DATA(1,J+12)  = YAWB
      DATA(1,J+13)  = PREF
      DATA(1,J+14)  = E
      DATA(1,J+15)  = DE
      DATA(1,J+16)  = DCA
      DATA(1,J+17)  = DCB
      WRITE (LI,105) XIMC,YAWC,P1,P23,P4,I,XIMA,YAWA,DCA,PREF,E,XIMB,
     *YAWB,DCB,RPM,DE
      IF ( LO .NE. 0 ) WRITE (LO,105) XIMC,YAWC,P1,P23,P4,I,XIMA,YAWA,DC
     *A,PREF,E,XIMB,YAWB,DCB,RPM,DE
      IF ( J .EQ. 61 ) GOTO 05
      IF ( J .EQ.141 ) GOTO 10
 04   WRITE (LI,106)
      READ  (LI,149) IDUM
      WRITE (LI,149) ( ICLR,I1=1,3)
      IF ( IDUM .NE. 2HGO ) GOTO 04
      J = J + 20
      I = I + 1
      GOTO  03
 05   WRITE (LI,107)
      READ  (LI,  *) YAWP
      YAWP = YAWP * 2
C     .................................................................
C     .                                                               .
C     .  Data acquasition of high speed data.                         .
C     .                                                               .
C     .................................................................
      WRITE (LI,108)
      IF (LO .NE. 0 ) WRITE (LO,108)
      WRITE (LI,104)
      IF (LO .NE. 0 ) WRITE (LO,104)
      DO  09  JI = 2,YAWP,2
      JJ = JI / 2
 06   WRITE (LI,109) JJ
      READ  (LI,149)IDUM
C     WRITE (LI,149) ( ICLR,I1=1,3)
      IF ( IDUM .NE. 2HGO ) GOTO 06
      AVRGA     = 0.0
      ICOUNT    =   0
      START     = 256
      STOP      = 256 + 256
      DO 61 I1 = START,STOP,1
      ICOUNT    = ICOUNT + 1
      IBLADE = I1 + 100000B
      CALL EXEC (3,19)
      CALL EXEC (1,19,IRPM,1,IBLADE)
      CALL EXEC (1,20,IBUFF,30,0,0)
      RBUFF     = 0.0
      DO 62 J1 = 1,30,1
      IBUFF(J1)= IAND(IBUFF(J1),MASK)
 62   RBUFF     = FLOAT ( IBUFF(J1) ) / 32768. + RBUFF
      DATA(JI,ICOUNT) = ((RBUFF*FSVLTG)/30)
      AVRGA               = AVRGA + DATA (JI,ICOUNT)
 61   CONTINUE
      AVRGA               = AVRGA / 256
C     DO 5454 I = 1,32,1
C5454 WRITE (6,1313) (J,DATA(JI,J), J = I,256,32 )
C1313 FORMAT (8(" DATA("I3")="F6.0))
      WRITE (1,222) AVRGA
 222  FORMAT(" AVRGA = "F12.6)
      AVRGB     = 0.0
      ICOUNT    =   0
      START     = 1696
      STOP      = 1696 + 256
      DO 64 I1 = START,STOP,1
      ICOUNT    = ICOUNT + 1
      IBLADE    = I1 + 100000B
      CALL EXEC (3,19)
      CALL EXEC (1,19,IRPM,1,IBLADE)
      CALL EXEC (1,20,IBUFF,30,1,0)
      RBUFF     = 0.0
      DO 63 J1 = 1,30,1
      IBUFF(J1)= IAND(IBUFF(J1),MASK)
 63   RBUFF     = FLOAT ( IBUFF(J1) ) / 32768. + RBUFF
      DATA(JI+1,ICOUNT) = ((RBUFF*FSVLTG)/30)
      AVRGB               = AVRGB + DATA (JI+1,ICOUNT)
 64   CONTINUE
```

Figure H-2. Listing of Data Acquisition Program &ABKUL.
(Continued on next page.)

```
          AVRGB                 = AVRGB / 256
C         DO 5455 I = 1,32,1
C5455     WRITE (6,1313) (J,DATA(JI+1,J),J = I,256,32)
          WRITE(1,333) AVRGB
    333   FORMAT(" AVRGB = "F12.6)
C        ..............................................................
C        .                                                            .
C        .    Get necessary steady state data !                       .
C        .                                                            .
C        ..............................................................
C         GOTO 099
          I = (JJ - 1) * 20 + 1
          DATA(20,I   ) = ACON  ( 4, 1,10)
          DATA(20,I+ 1) = ACON  ( 4, 2,10)
          DATA(20,I+ 2) = ACON  ( 4, 6,10)
          DATA(20,I+ 3) = ACON  ( 4, 7,10)
          DATA(20,I+ 4) = ACON  ( 4, 8,10)
          DATA(20,I+ 5) = SCANR( 8,17, 2)
          DATA(20,I+ 6) = SCANR( 8,25, 1)
          DATA(20,I+ 7) = SCANR( 8,32, 1)
          DATA(20,I+ 8) = SCANR( 8,33, 1)
          DATA(20,I+ 9) = SCANR( 8,34, 1)
          DATA(20,I+10) = SCANR( 8,35, 1)
          DATA(20,I+11) = SCANR( 8,36, 1)
          DATA(20,I+12) = SCANR( 8,37, 1)
          DATA(20,I+13) = SCANR( 8,39, 1)
          DATA(20,I+14) = SCANR(15,18, 1)
          DATA(20,I+15) = SCANR(15,19, 1)
          DATA(20,I+16) = SCANR(15,52, 1)
          DATA(20,I+17) = SCANR(15,53, 1)
          DATA(20,I+18) = AVRGA
          DATA(20,I+19) = AVRGB
          WRITE (LI,105) DATA(20,I+7),DATA(20,I+8),DATA(20,I+2),DATA(20,I+3)
         *,DATA(20,I+4),JJ,DATA(20,I+9),DATA(20,I+10),DATA(20,I+16),
         *DATA(20,I+13),DATA(20,I+14),DATA(20,I+11),DATA(20,I+12),
         *DATA(20,I+17),DATA(20,I+5),DATA(20,I+15)
          WRITE (LI,112) AVRGA,AVRGB
          IF ( LO .NE. 0 ) WRITE (LO,105)  DATA(20,I+7),DATA(20,I+8),DATA(20
         *,I+2),DATA(20,I+3),DATA(20,I+4),JJ,DATA(20,I+9),DATA(20,I+10),DATA
         *(20,I+16),DATA(20,I+13),DATA(20,I+14),DATA(20,I+11),DATA(20,I+12),
         *DATA(20,I+17),DATA(20,I+5),DATA(20,I+15)
          IF ( LO .NE. 0 ) WRITE (LO,112) AVRGA,AVRGB
C        ..............................................................
C        .                                                            .
C        .    Next yaw position.                                      .
C        .                                                            .
C        ..............................................................
     09   CONTINUE
          J = 81
          GOTO 02
     10   CONTINUE
C        ..............................................................
C        .                                                            .
C        .       Release interface bus and devices from remote control .
C        .                                                            .
C        ..............................................................
          CALL  CLEAR  (7,1)
          CALL  LOCL      (7)

          DO 11 I = 1,4,1
          J         = (I-1) * 20 + 17
          X(I)      = DATA(1, J)
          JJ        = J - 3
     11   Y(I)      = DATA(1,JJ)
          CALL  CURVE (4,X,Y,SLOPE,SECON)
          DATA(1,160) = SLOPE
          DATA(1,161) = SECON
          DO 12 I = 1,4,1
          J         = (I-1) * 20 + 18
          X(I)      = DATA(1, J)
          JJ        = J - 4
     12   Y(I)      = DATA(1,JJ)
          CALL  CURVE (4,X,Y,SLOPE,SECON)
          DATA(1,170) = SLOPE
          DATA(1,171) = SECON
          DO 13 I = 1,4,1
          J         = (I-1) * 20 + 97
          X(I)      = DATA(1, J)
          JJ        = J - 3
     13   Y(I)      = DATA(1,JJ)
```

Figure H-2. Listing of Data Acquisition Program &ABKUL.
(Continued on next page.)

```
      CALL  CURVE (4,X,Y,SLOPE,SECON)
      DATA(1,180) = SLOPE
      DATA(1,181) = SECON
      DO 14 I = 1,4,1
      J        = (I-1) * 20 + 98
      X(I)     = DATA(1, J)
      JJ       = J - 4
   14 Y(I)     = DATA(1,JJ)
      CALL  CURVE (4,X,Y,SLOPE,SECON)
      DATA(1,190) = SLOPE
      DATA(1,191) = SECON
      WRITE (LI,110) ( DATA(1,I),DATA(1,I+1),I = 160,190,10)
      IF(LO.NE.0) WRITE(LO,110) ( DATA(1,I),DATA(1,I+1),I = 160,190,10)
      WRITE (LI,111)
      READ  (LI,149) IFILE
      CALL  CREAT (IDCB,IERR,IFILE,ISIZE,ITYPE,ISECU,ICR,IDCBS)
      II = 1
      IF ( IERR .LT. 0 ) WRITE (1,1111) II,IERR
      CALL  OPEN (IDCB,IERR,IFILE,IOPTN,ISECU,ICR,IDCBS)
      II = 2
      IF ( IERR .LT. 0 ) WRITE (1,1111) II,IERR
      CALL  WRITF (IDCB,IERR,DATA,IL)
      II = 3
      IF ( IERR .LT. 0 ) WRITE (1,1111) II,IERR
      CALL  CLOSE (IDCB,IERR,0)
      II = 4
      IF ( IERR .LT. 0 ) WRITE (1,1111) II,IERR
      STOP 7777
      END
```

Figure H-2. Listing of Data Acquisition Program &ABKUL.

APPENDIX I

PROCESSING PROGRAMS &SPLIT AND &WAVE FOR TEST DATA

As stated in 6.3 a plot of the acquired high speed data is very desirable since it represents the fastest way to judge the quality of the data. As the graphics software requires much storage space within a program, it is not possible to read the complete data file into a plot program. A utility program--&SPLIT--has been created which splits the data array into two smaller arrays containing either A or B probe data. These arrays contain the data for the on-line calibration and steady state also. They are both stored under different names, which are operator input.

Since program &SPLIT is a very short and simple program, only a listing is given in Fig. I-1. Explanations are given as needed within the listing. The two newly created files are stored on the same cartridge as the original raw data file.

Program &WAVE provides means to read the smaller data files and to plot their contents. If the variable POS is assigned to be the circumferential position of the probe readings where the starting position is set to 1 and the end position to 256, the pressure distribution can be expressed as a function P = P(pos) for all nine yaw angles. These functions can be plotted by program &WAVE. The plot is a straight line connection of all points.

As mentioned in 6.3 program &WAVE serves two purposes: plotting Kulite data from an existing file and acquiring data from any of the 16 A/D channels and plotting it right away. The decision as to which of the two options shall be used has to be made first by the operator. If it is desired to plot data from a data file, the operator has to key in the file name and the cartridge reference number. This file is then read into a data array. For each probe yaw angle setting there is one pressure distribution P = P(POS) and the operator is asked to specify the one he wants to plot. The choice of plotting on the CRT screen or the X-Y plotter has to be made as well as whether a whole new frame for the plot is needed. Without further input the graph is developed. Other data from the same file can be plotted without rerunning the program or it can be stopped at this point.

If the second feature of the program should be exercised, it has to be specified at the very beginning, when asked for this decision. An A/D channel number has to be entered which corresponds to the Kulite transducer that shall be observed. The number of samples to be taken at each of the 256 positions also has to be put in. This initializes the data acquisition process. Once all the data is acquired, the operator has to decide whether he needs a new frame or not and where he would like to have his plot (CRT or X-Y plotter). As soon as the plot is dumped, the program can either be stopped or started from the very beginning.

Figure I-2 shows a flow chart of program &WAVE, while Fig. I-3 is a listing.

Variable	Type	Description
AD	Integer	Dummy Variable
CHANL	Integer	A/D channel number
DATA(11,256)	Real	Data Array
FSVLTG	Real	Calibration factor for Kulite probe reading
IBUFF(99)	Integer	Array for Kulite sample values
IBUM	Integer	Dummy variable
ICR	Integer	Cartridge reference number
ID	Integer	
IDCB(144)	Integer	Data control block
IDCBS	Integer	Data control block length
IDUM	Integer	Dummy variable
IFILE(3)	Integer	Array containing file name
IGCB(192)	Integer	Graphics control block
IL	Integer	Total number of words stored in data file (two words for one value)
ISECU	Integer	Security code
ISIZE(2)	Integer	Array to specify file dimensions
ITYPE	Integer	Type of data file
LI	Integer	Input device number
LU	Integer	Output device (screen/plotter) number
MASK	Integer	Masking variable
N	Integer	Number of samples to be averaged

Variable	Type	Description
RBUFF	Real	Real value of single sample
RBUFO	Real	Sum of all real value samples for one position
X(256)	Real	Real data array
Y(256)	Real	Real data array

```
&SPLIT T=00004 IS ON CR00026 USING 00021 BLKS R=0000

FTN4,L
      PROGRAM SPLIT(3,99)
C     ..................................................................
C     .                                                                .
C     .   This program splits the large data file as created by program.
C     .   ABKUL into two seperate data files.                          .
C     .   One contains the waveforms of the A-probe and the other the  .
C     .   one from the B-probe!                                        .
C     .                                                                .
C     ..................................................................
      REAL     DATA(20,256),DATAS(11,256)
      INTEGER  IDCB(144),IFILE(3),ISIZE(2)
      DATA     IDCBS    /   144/
      DATA     ISECU    /    00/
      DATA     ITYPE    /     1/
      DATA     ISIZE(2)/    128/
  101 FORMAT(" ENTER THE NAME OF THE RAW DATA FILE :  ")
  102 FORMAT(" ENTER THE CARTRIDGE REFERENCE NUMBER:  ")
  103 FORMAT(" ENTER THE NAME FOR THE FILE CONTAINING A-PROBE DATA!")
  104 FORMAT(" ENTER THE NAME FOR THE FILE CONTAINING B-PROBE DATA!")
  149 FORMAT((3A2))
 1111 FORMAT(" STATEMENT # :"I2" ERROR # : "I4" DISCOVERED!")
      ISIZE(1)   =    80
      IL         = 10240
C     ..................................................................
C     .                                                                .
C     .   READ RAW DATA FILE INTO ARRAY DATA(20,256) !                 .
C     .                                                                .
C     ..................................................................
      WRITE (1,101)
      READ  (1,149) IFILE
      WRITE (1,102)
      READ  (1,  *) ICR
      CALL OPEN (IDCB,IERR,IFILE,IOPTN,ISECU,ICR,IDCBS)
      JJ = 1
      IF ( IERR .LT. 0 ) WRITE (1,1111) JJ,IERR
      CALL READF (IDCB,IERR,DATA,IL,LEN,1)
      JJ = 2
      IF (IERR .LT. 0 ) WRITE(1,1111) JJ,IERR
      CALL CLOSE (IDCB,IERR,0)
      JJ = 3
      IF (IERR .LT. 0 ) WRITE(1,1111) JJ,IERR
C     ..................................................................
C     .                                                                .
C     .    READ A-PROBE DATA INTO SEPARATE ARRAY .                     .
C     .                                                                .
C     ..................................................................

      DO 05       J = 1,   9,1
      DO 05       I = 1,256,1
      J1            =   J * 2
      J2            =   J + 1
      DATAS(J2,I) = DATA(J1,I)
      DATAS( 1,I) = DATA(1 ,I)
   05 DATAS(11,I) = DATA(20,I)
      ISIZE(1)      =    44
      IL            = 5632
C     ..................................................................
C     .                                                                .
C     .    READ FILENAME FOR A-PROBE DATA AND STORE A-PROBE DATA.      .
C     .                                                                .
C     ..................................................................

      WRITE (1,103)
      READ  (1,149) IFILE
      CALL  CREAT (IDCB,IERR,IFILE,ISIZE,ITYPE,ISECU,ICR,IDCBS)
      JJ = 4
      IF (IERR .LT. 0 ) WRITE(1,1111) JJ,IERR
      CALL  OPEN (IDCB,IERR,IFILE,IOPTN,ISECU,ICR,IDCBS)
      JJ = 5
      IF (IERR .LT. 0 ) WRITE(1,1111) JJ,IERR
      CALL  WRITF (IDCB,IERR,DATAS,IL)
      JJ = 6
      IF (IERR .LT. 0 ) WRITE(1,1111) JJ,IERR
      CALL  CLOSE (IDCB,IERR,0)
      JJ = 7
      IF (IERR .LT. 0 ) WRITE(1,1111) JJ,IERR
C     ..................................................................
```

Figure I-1. Listing Program to Split Up Big Raw Data Array From A-B Probe Into Smaller Arrays: &SPLIT.
(Continued on next page.)

```
C     .                                                              .
C     .    READ B-PROBE DATA INTO SEPARATE ARRAY .                   .
C     .                                                              .
C     ................................................................
      DO 07      J = 1,  9,1
      DO 07      I = 1,256,1
      J1           =   ( J * 2 ) + 1
      J2           =     J + 1
      DATAS(J2,I) = DATA(J1,I)
      DATAS(1 ,I) = DATA(1 ,I)
   07 DATAS(11,I) = DATA(20,I)
C     ................................................................
C     .                                                              .
C     .     READ FILENAME FOR B-PROBE DATA AND STORE B-PROBE DATA.   .
C     .                                                              .
C     ................................................................
      WRITE (1,104)
      READ  (1,149) IFILE
      CALL  CREAT (IDCB,IERR,IFILE,ISIZE,ITYPE,ISECU,ICR,IDCBS)
      JJ = 7
      IF (IERR .LT. 0 ) WRITE(1,1111) JJ,IERR
      CALL  OPEN (IDCB,IERR,IFILE,IOPTN,ISECU,ICR,IDCBS)
      JJ = 8
      IF (IERR .LT. 0 ) WRITE(1,1111) JJ,IERR
      CALL  WRITF (IDCB,IERR,DATAS,IL)
      JJ = 9
      IF (IERR .LT. 0 ) WRITE(1,1111) JJ,IERR
      CALL  CLOSE (IDCB,IERR,0)
      JJ =10
      IF (IERR .LT. 0 ) WRITE(1,1111) JJ,IERR
      STOP 7777
      END
```

Figure I-1. Listing of Program to Split Up Big Raw Data Array From A-B Probe Into Two Smaller Arrays: &SPLIT.

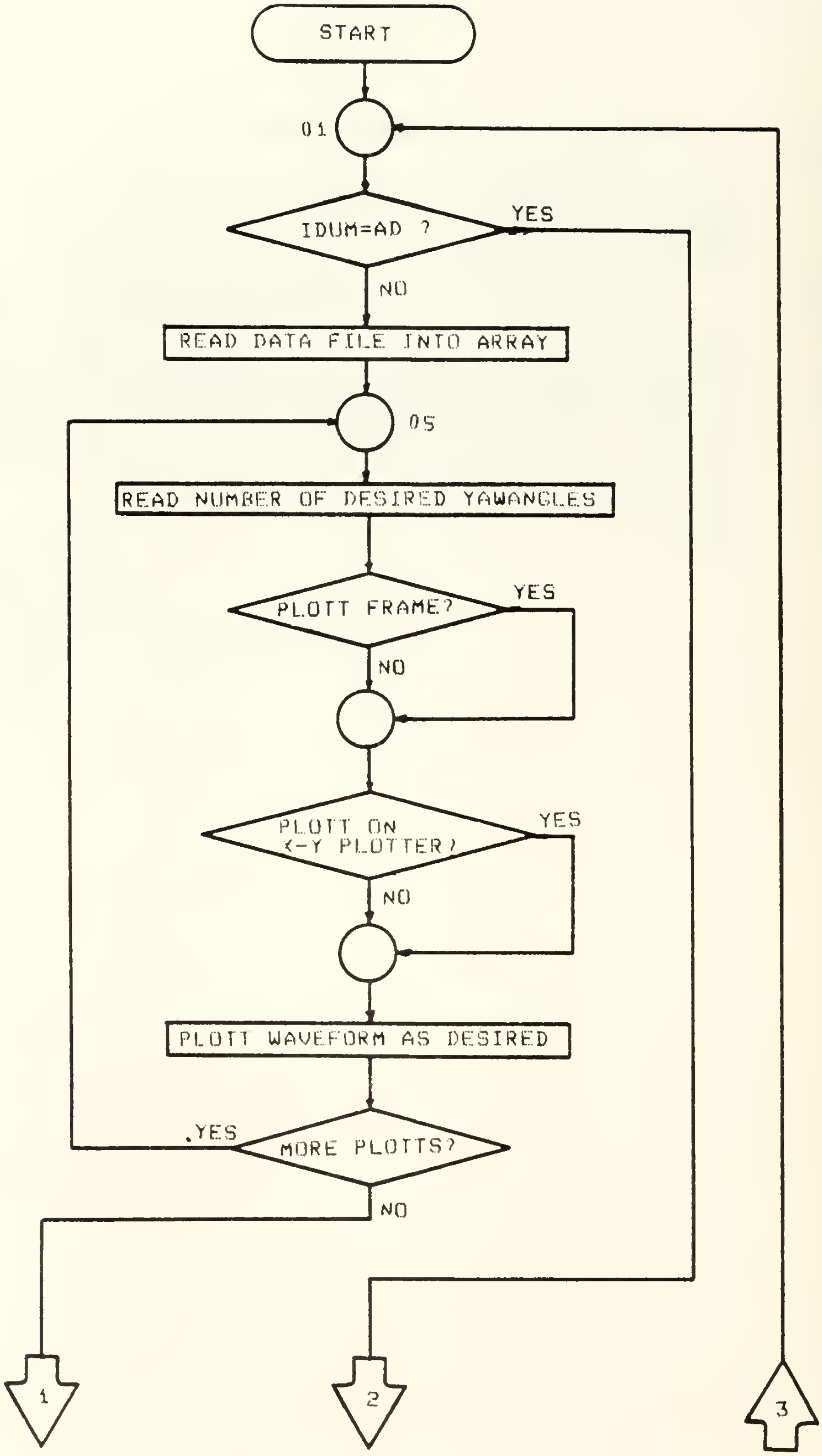


Figure I-2. Flow Chart of Data Acquisition and Plotter Program &WA

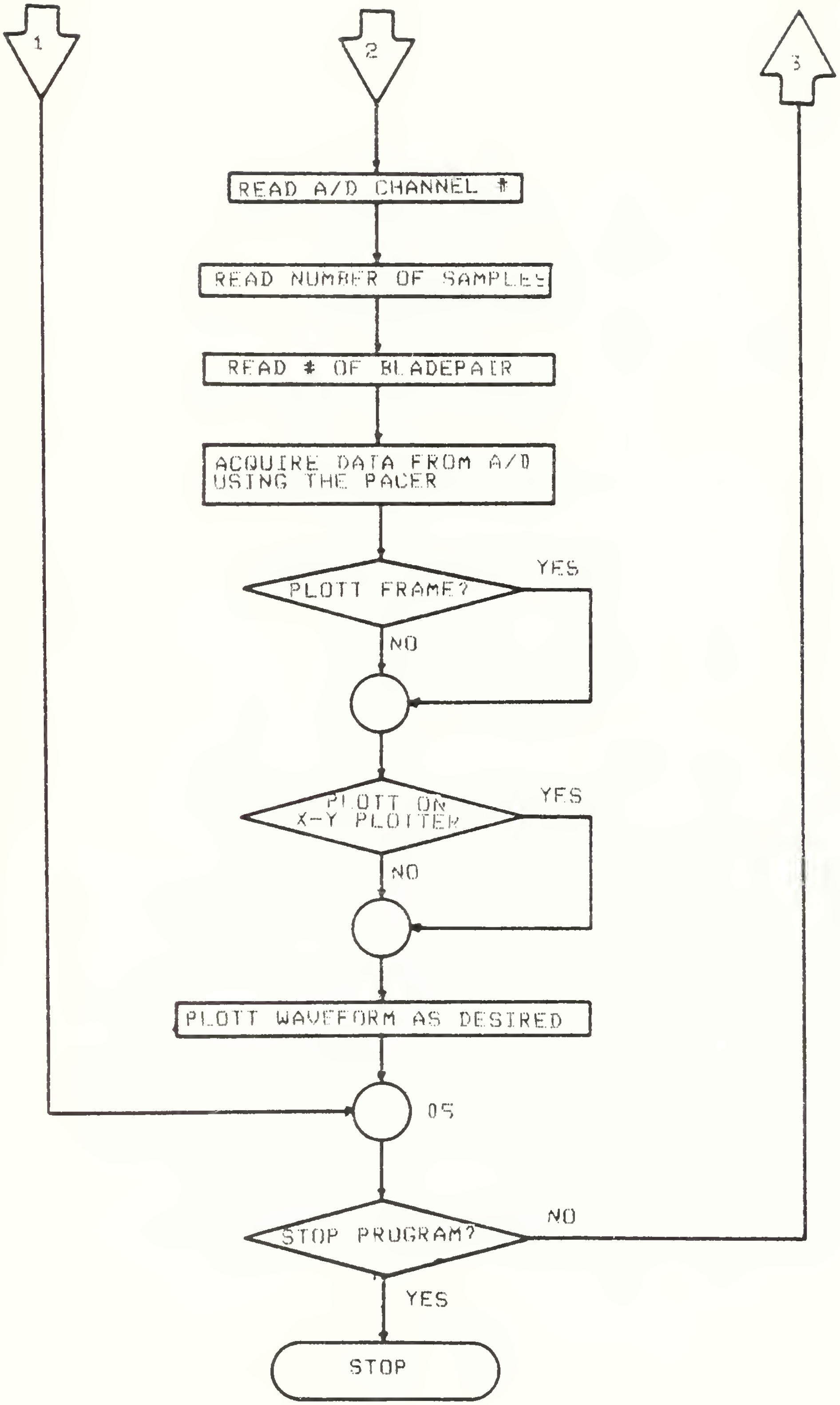


Figure I-2. Flow Chart of Data Acquisition and Plotter Program &WAVE.

```
&WAVE  T=00004 IS ON CR00027 USING 00022 BLKS R=0000

FTN4,L
      PROGRAM WAVE (3,99)
C     ..................................................................
C     .                                                                .
C     .    This is program WAVE                                        .
C     ..   It plotts waveforms as read from either :                   .
C     .    a data file created using test data from the TX-compressor  .
C     .    or from a specified AD channel right away.                  .
C     .                                                                .
C     ..................................................................
      DIMENSION IGCB(192),IBUFF(99)
      REAL      DATA(11,256),X(256),Y(256)
      INTEGER   IDCB(144),IFILE(3),ISIZE(2),N,CHANL
      DATA      IDCBS    /  144/
      DATA      ISECU    /   00/
      DATA      ITYPE    /    1/
      DATA      IL       / 5632/
      DATA      ISIZE(1) /   44/
      DATA      ISIZE(2) /  128/
      DATA      MASK     / 177700B/
      DATA      FSVLTG   / .1E01/

 100  FORMAT (" This is program WAVE."/" It can plott a waveform as read
     * form the A/d or from a data file."/" Decide now, which of the two
     * options you want!"/" Key AD if you want to take a new reading. An
     *ythingelse"/" will ask for further informations for a data file.")
 101  FORMAT ("Enter the name of the data file!")
 102  FORMAT ("Enter the cartridge ref. number!")
 103  FORMAT(" Do you want another waveform to be plotted?"/" Enter yes,
     * if so, anything else if not!")
 104  FORMAT(" Do you want to stop this program or plot some more waves?
     *"/" If you are going to stop it, just key STOP. Anything else will
     * give you further instructions!")
 105  FORMAT (/12X,5(2X,F10.6)/5X,I2,5X,5(2X,F10.6)/12X,5(2X,F10.6))
 107  FORMAT(" Do you need a complete new frame?"/" Answer YES or NO!")
 108  FORMAT(" If you want the plott on the plotter, key PL, anythingels
     *e for the terminal !")
 113  FORMAT(" You decided to to get a waveform from the AD!"/"Enter the
     * following now : AD channel")
 114  FORMAT(" Number of repetitions, bladepair (1-9) :")
 115  FORMAT(" Enter the corresponding number for the waveform you want
     *to draw!"/" The arrangement is:"/" Yaw pos #         1          2
     *        3                    9"/9X" DATA( 1,J), DATA(2,J), DATA(3,J), ...
     *...DATA( 9,J)  -   Probe"/)
 116  FORMAT(" Do you want a plot of another waveform?"/" If so, key YE.
     *Any other key will stop the program!")
 149  FORMAT ((3A2))
1111  FORMAT (" STATEMENT # :"I3" ERROR # : "I4" DETECTED")
      LI = LOGLU(ISESSN)
  001 WRITE (LI,100)
      READ  (LI,149) IDUM
      IF ( IDUM .EQ. 2HAD ) GOTO 025
      WRITE (LI,101)
      READ  (LI,149) IFILE
      WRITE (LI,102)
      READ  (LI,  *) ICR
      CALL OPEN  (IDCB,IERR,IFILE,IOPTN,ISECU,ICR,IDCBS)
      JJ = 1
      IF (IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
      CALL READF (IDCB,IERR,DATA,IL,LEN,1)
      JJ = 2
      IF (IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
      JJ = 3
      CALL CLOSE (IDCB,IERR,0)
      IF (IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
  005 WRITE (LI,115)
      READ  (LI,  *) I
      I1 = I + 1
      XK = 1.0
      DO 010 J = 1,256,1
      X(J)       = J * XK
  010 Y(J)       = DATA(I1,J)
      LU         = 1
      ID         = 1
      WRITE (LI,107)
      READ  (LI,149) IDUM
      WRITE (LI,108)
      READ  (LI,149) IBUM
```

Figure I-3. Listing of Program to Plott Raw Data Waveforms: &WAVE.
(Continued on next page.)

```
      IF (IBUM .EQ. 2HPL ) ID = 2
      IF (ID   .EQ. 2    ) LU = 13
      CALL PLOTR (IGCB,ID,1,LU)
      CALL SETAR (IGCB,1.5)
      CALL VIEWP (IGCB,20.,100.,20.,68.)
      CALL WINDW (IGCB,0.,256.,-1.0,1.0)
      IF ( IDUM .NE. 2HYE ) GOTO 015
      CALL FXD   (IGCB,2)
      CALL LGRID (IGCB,-16.,.10,0.0,0.0,4.,2.,1.)
  015 CONTINUE
      CALL MOVE  (IGCB,X(1),Y(1))
      DO 020 J = 2,256,1
  020 CALL DRAW (IGCB,X(J),Y(J))
      WRITE (LI,103)
      READ  (LI,149) IDUM
      IF ( IDUM .EQ. 2HYE ) GOTO 05
      GOTO 050
  025 WRITE (LI,113)
      READ  (LI,  *) ICHAN
      WRITE (LI,114)
      READ  (LI,  *) N,IBLADE
      ISTART   = (IBLADE-1) * 256 + 1
      ISTOP    = ISTART + 255
      I1       = 0
      DO 035 I = ISTART,ISTOP,1
      I1       = I1 + 1
      IBLADE   = I + 256  + 100000B
      CALL EXEC (3,19)
      CALL EXEC (1,19,IRPM,1,IBLADE)
      CALL EXEC (1,20,IBUFF,N,ICHAN,0)
      RBUFO = 0.0
      DO 030 J = 1,N,1
      IBUFF(J) = IAND(IBUFF(J),MASK)
      RBUFF    = FLOAT(IBUFF(J))/32768.
  030 RBUFO    = RBUFF + RBUFO
  035 Y(I1)    = ((RBUFO*FSVLTG)/N)
      LU = 1
      ID = 1
      WRITE (LI,107)
      READ  (LI,149) IDUM
      WRITE (LI,108)
      READ  (LI,149) IBUM
      IF (IBUM .EQ. 2HPL ) ID = 2
      IF (ID   .EQ. 2    ) LU = 13
      CALL PLOTR (IGCB,ID,1,LU)
      CALL SETAR (IGCB,1.5)
      CALL VIEWP (IGCB,20.,100.,20.,68.)
      CALL WINDW (IGCB,0.,256.,-1.0,1.0)
      IF ( IDUM .NE. 2HYE ) GOTO 040
      CALL FXD   (IGCB,2)
      CALL LGRID (IGCB,-16.,.10,0.0,0.0,4.,2.,1.)
  040 CONTINUE
      CALL MOVE  (IGCB,1,Y(1))
      DO 045 J = 2,256,1
      X(J)       = J * 1.0
  045 CALL DRAW (IGCB,X(J),Y(J))

  050 WRITE (LI,104)
      READ  (LI,149) IDUM
      IF ( IDUM .NE. 2HST ) GOTO 01
      STOP 7777
      END
```

Figure I-3. Listing of Program to Plott Raw Data Waveforms: &WAVE.

APPENDIX J

DATA REDUCTION PROGRAM &ABRED

Program &ABRED was explained almost completely in chapter 6.4. More detailed explanations shall be given in here where they are needed. Figure J-1 shows a self-explanatory flow chart of the program while Fig. J-2 is a complete listing.

From the flow chart it is obvious that the first and bigger part of the program deals with overall flow measurements from the combination probe. The data reduction of these measurements is not explained since Ref. 1 deals with this in great detail. It should be mentioned that the raw data used for the combination probe data reduction is the average of the raw data which was acquired along with the acquisition of any set of Kulite probe data. Thus the results of the combination probe represent one average flow vector which is assumed to be constant throughout the data acquisition process. As the Kulite data used for the on-line calibration is derived from the whole raw data acquired also, this seems to be a reasonable way. The principle of the on-line calibration was described in chapter 6.1 already. If a print-out of the control parameters was chosen, the result of the on-line calibration will be displayed in the form of a linear equation relating A and B probe pressures to voltages.

The results of the on-line calibration are first applied to the dc-level values from the A and B probe in order to calculate the average flow vector. Chapter 6.4 shows the results of this process. The procedure used to derive these values is in principal the same as the one used to calculate flow vector quantities for the individual measurements. In order to check the quality of the data reduction, an output of the A and B probe results as derived from their approximations can be produced. The yaw and pitch angle as well as Mach number are derived from the approximation results and printed out. These values can be compared to those derived from the combination probe (see 6.4).

Then the DO-loop for the reduction of individual data points is started at the position (ISTART) determined earlier. For any of these positions the results of the on-line calibration is applied to the raw data first, so that absolute pressure values exist. The data reduction procedure as described in 6.4 is then applied to these values. Using the local Mach number as well as the total pressure as derived from the A probe, pressure coefficients Cp_A are derived as functions of yaw angle and can be printed if desired. The examination of these values proved to be very helpful in the evaluation of the quality of the achieved result.

Since the A probe has only one calibration curve Cp_A as a function of yaw angle, as long as the pitch angle and Mach number do not exceed the range of the calibration, for any measured position the same curve should be resolved. The use made of this fact so far is described in chapter 7.

When the DO-loop for all described positions is completed, the reduced data is stored in a file. Only pitch and yaw angle and Mach number (or x) are stored, since they are sufficient to describe the individual flow vectors.

Common Block Identifier	Variable
DTA2	X1, Y

Variable	Type	Description
AAO	Real	A probe yaw angle for aligned flow
ABO	Real	B probe yaw angle corresponding to max. probe output
ASL	Real	A probe yaw angle 63° left of flow aligned yaw angle
ASR	Real	A probe yaw angle 63° right of flow aligned yaw angle
BETA	Real	Dimensionless pressure coefficient
BETA2	Real	Relative rotor exit flow angle
COECPB(7,7)	Real	Data array for coefficients of 3-D CPOB approximation
COEF(7)	Real	Data array for 2-D approximation coefficients
COEKP(7,7)	Real	Data array for coefficients of 3-D Kulite pitch angle approximation
COEKX(7,7)	Real	Data array for coefficients of 3-D Kulite Mach number approximation
COEOP(7,7)	Real	Data array for coefficients of 3-D combination probe pitch angle approximation

Variable	Type	Description
COEOX(7,7)	Real	Data array for coefficients of 3-D combination probe Mach number approximation
CPA	Real	Pressure coefficient from A probe
CPAMAX	Real	Maximum pressure coefficient from A probe
CPBMAX	Real	Maximum pressure coefficient from B probe
CPOA(6)	Real	Data array for 2-D approximation of A probe pressure coefficients
DATA(20,256)	Real	Data array containing the raw data
DEAMAX	Real	First derivative of approximated function EA (voltage A probe) of yaw angle for maximum of EA
DEBMA	Real	First derivative of approximated function EB (voltage B probe) of yaw angle for maximum of EB
DELTA	Real	Pressure coefficient
DP	Real	Pressure difference for two pressure values corresponding to two yaw angles which are separated by DX
DPA	Real	Difference between actual A probe pressure and value derived from polynomial approximation at each yaw position.
DPB	Real	Difference between actual B probe pressure and value derived from polynomial approximation at each yaw position
DPX	Real	First derivative of the function $P_A(\alpha) - P_A(\alpha - \Delta\alpha)$
DX	Real	Given spread in yaw angle between PSAL and PSAR
EAMAX	Real	Maximum voltage from the A probe
EBMAX	Real	Maximum voltage from the B probe

Variable	Type	Description
EQ3	Real	CPOA - maximum pressure coefficient of A probe (used in on-line calibration)
EQ5	Real	CPOB - maximum pressure coefficient of B probe (used in on-line calibration)
GAMMA	Real	Pressure coefficient
ICR	Integer	Cartridge reference number
IDCB(144)	Integer	Data control block
IDCBS	Integer	Control block length (of IDCB)
IFILE(3)	Integer	Array containing file name
IL	Integer	Total number of words read from data file (two words for one value)
IPRINT	Integer	Decision variable (control parameters yes or no?)
IPRIN1	Integer	Decision variable (calibration coefficients yes or no?)
ISECU	Integer	Security code
ISIZE(2)	Integer	Array to specify file dimensions
ITYPE	Integer	Type of data file
ICLR(3)	Integer	Command to clear line above cursor
LI	Integer	Input device number
LO	Integer	Output device number
NOLF	Integer	No line feed command
NOCR	Integer	No carriage return command
PA(9)	Real	A probe pressure values from individual measurements
PAA(9)	Real	A probe pressure values from averaged (dc-level) measurements
PAB(9)	Real	B probe pressure values from averaged (dc-level) measurements

Variable	Type	Description
PAC(9)	Real	Calculated values of A probe
PAMAX	Real	Maximum pressure value of A probe output as function of yaw angle
PB(9)	Real	B probe pressure values from individual measurements
PBARO	Real	Barometric pressure
PBC	Real	Calculated values of B probe
PBMAX	Real	Maximum pressure value of B probe output as function of yaw angle
PHI	Real	Pitch angle
PKB	Real	Maximum absolute average value of B probe pressure
PREF	Real	Average value of Kulite reference pressure
PREFP(9)	Real	Array of reference pressures for all 9 independent yaw positions
PSA	Real	Static pressure equivalent of A probe
PSAL	Real	Pressure reading of A probe for a yaw angle 63° to the left of the flow aligned yaw angle
PSAR	Real	Pressure reading of A probe for a yaw angle 63° to the right of the flow aligned yaw angle
PSTAT	Real	Static pressure
PSTATA	Real	Static pressure minus Kulite reference pressure
PTOTAL	Real	Total pressure
POA	Real	Maximum pressure output of A probe (on-line calibration)
POB	Real	Maximum pressure output of B probe (on-line calibration)

Variable	Type	Description
P1	Real	
P23	Real	Pressure values of combination probe
P4	Real	
RADIS	Real	Radius of probe tip location
RDATA(3,256)	Real	Reduced data array
RPM	Real	Compressor speed
SECTA	Real	Intercept A probe
SECTB	Real	Intercept B probe
SLOPEA	Real	Slope A probe
SLOPEB	Real	Slope B probe
TT2	Real	Total temperature at rotor exit
U	Real	Circumferential rotor speed
XM	Real	Mach number
XU	Real	Dimensionless circumferential rotor speed
XVEL	Real	Mach number equivalent dimensionless speed
X0	Real	Starting value for the iteration to find PSAL and PSAR
X1(256)	Real	Data array for 2-D approximations
Y(256)	Real	Data array for 2-D approximations
YAW	Real	Yaw angle
YAWA(9)	Real	Array containing A probe yaw angles
YAWB(9)	Real	Array containing B probe yaw angles

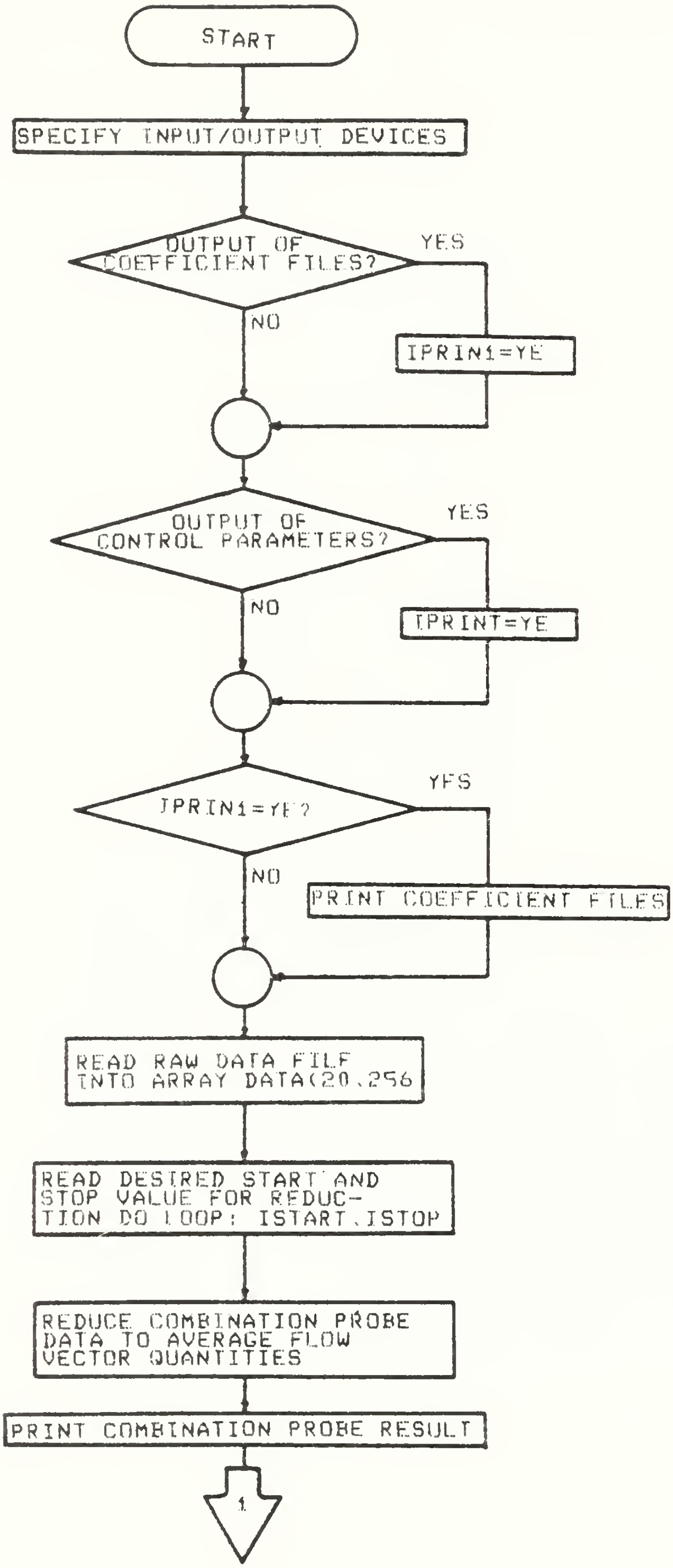


Figure J-1. Flow Chart of Data Reduction Program &ABRED.

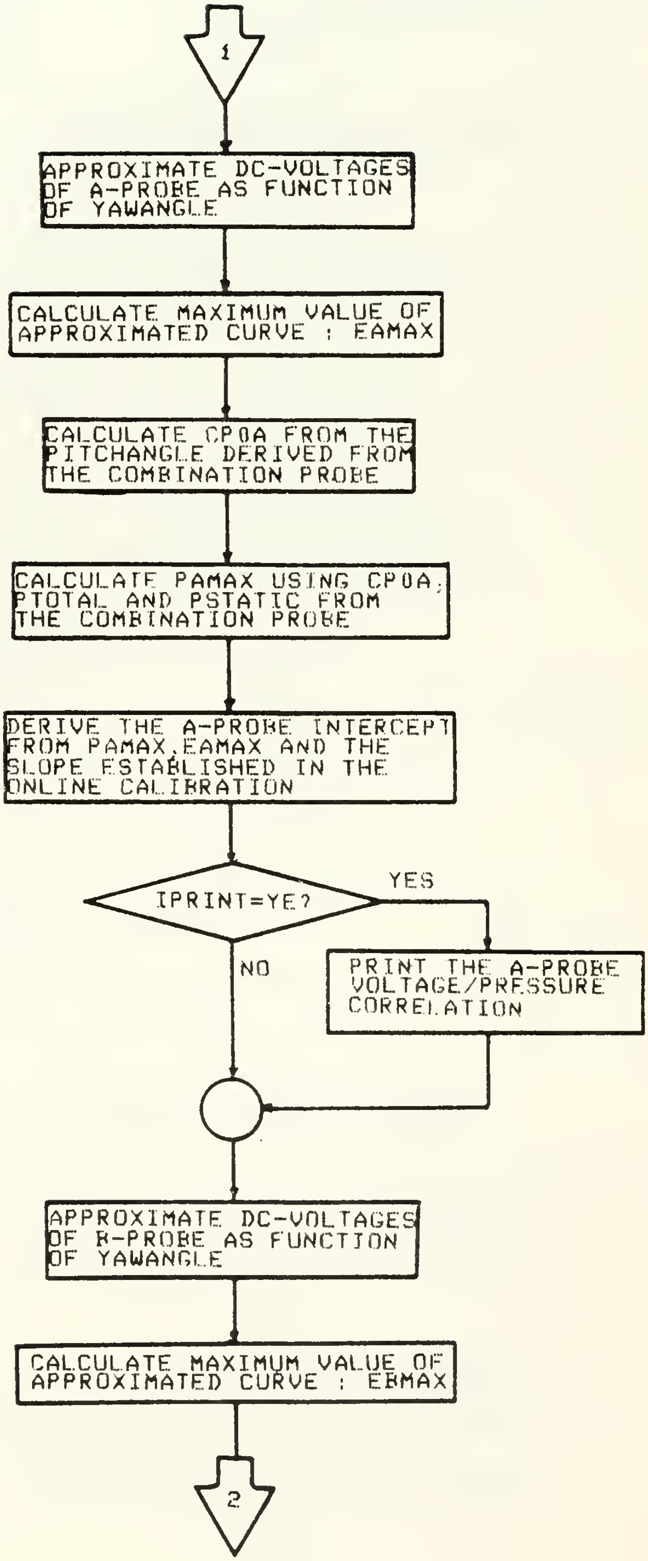


Figure J-1. Flow Chart of Data Reduction Program &ABRED.
con't

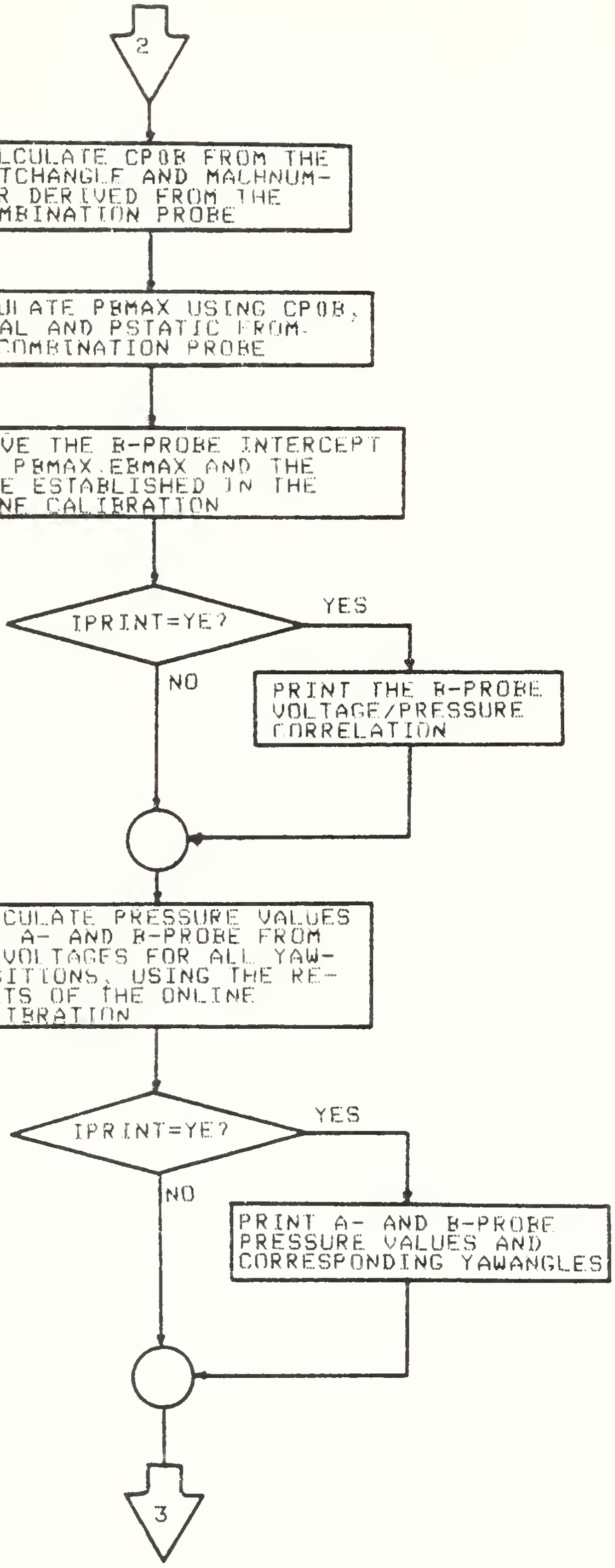


Figure J-1. Flow Chart of Data Reduction Program &ABRED.
con't

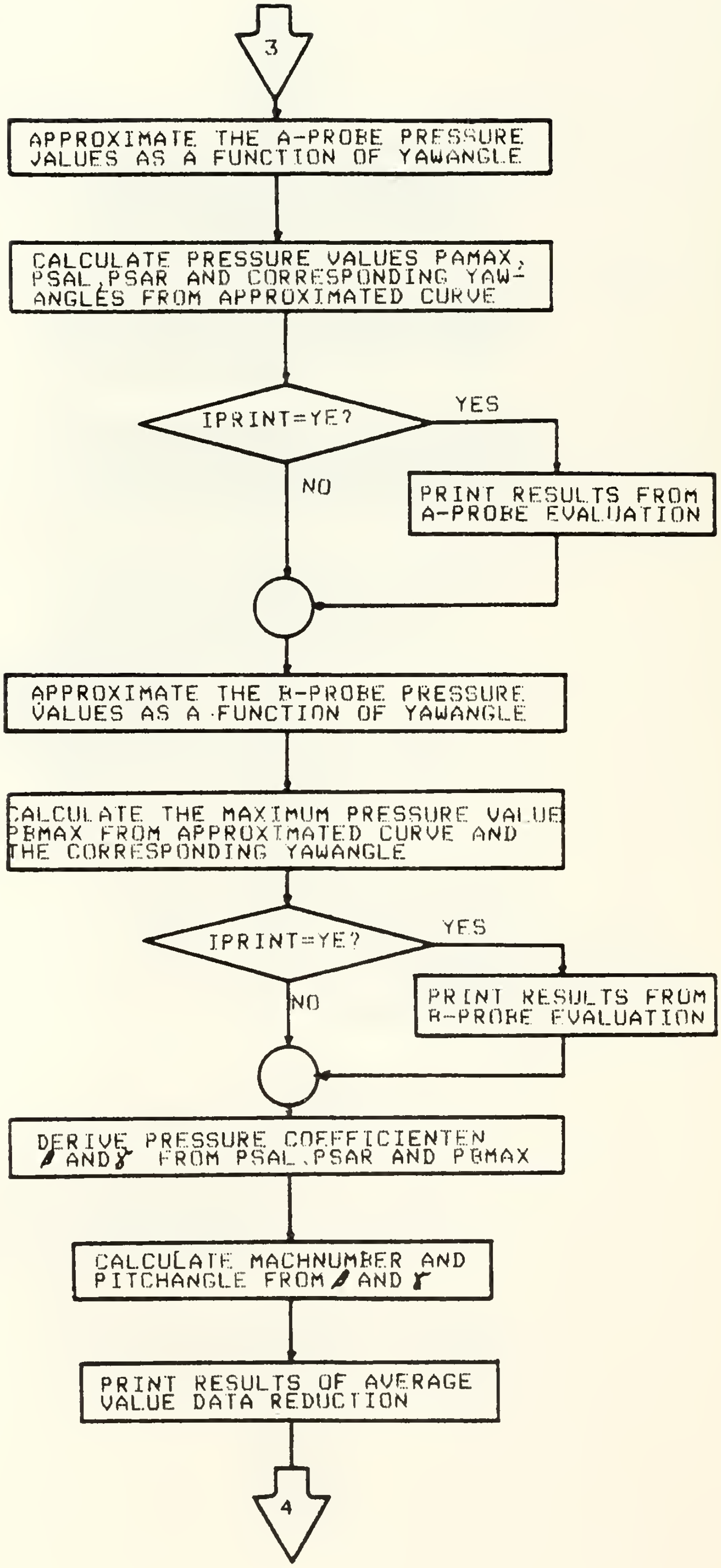


Figure J-1. Flow Chart of Data Reduction Program &ABRED.
con't

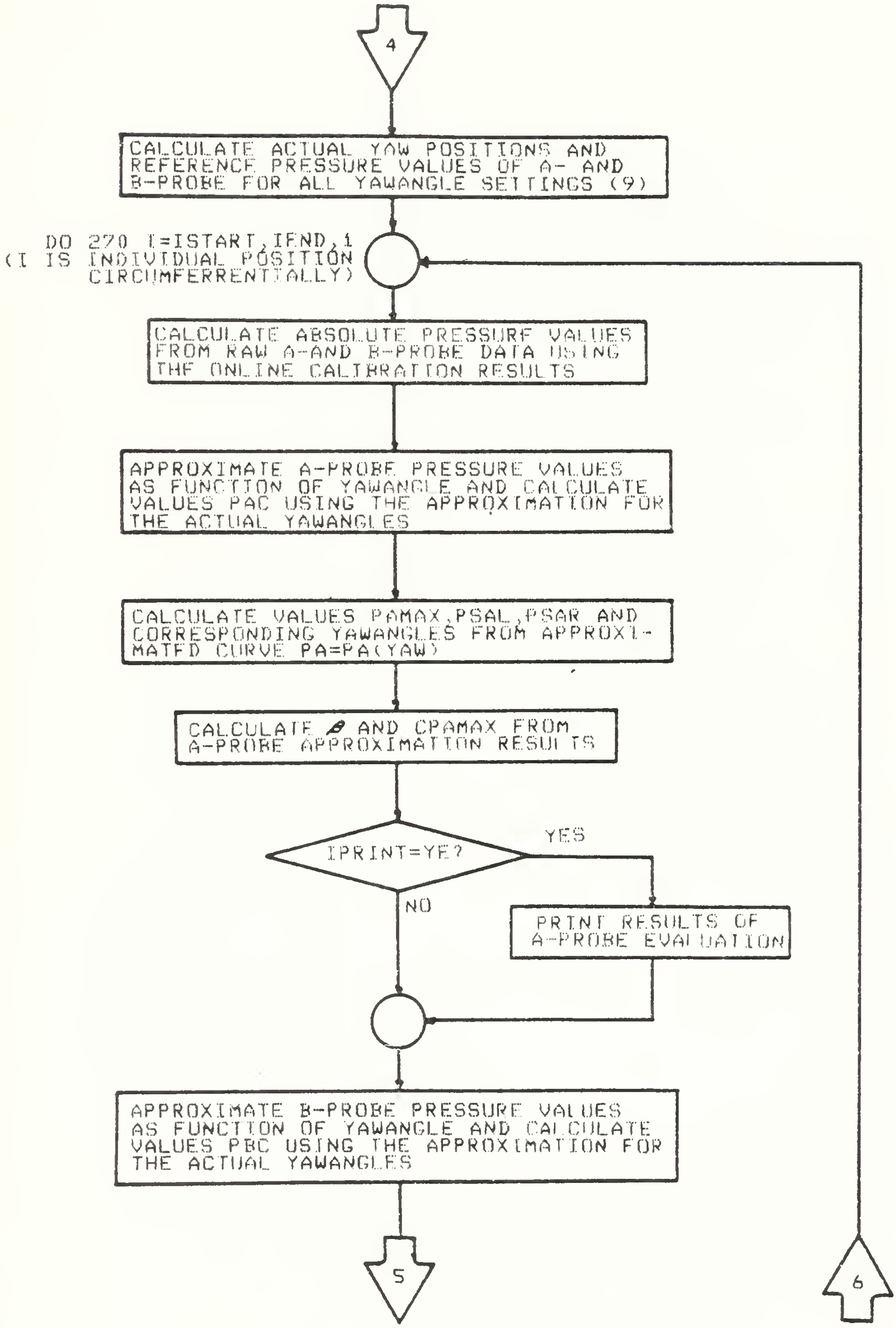


Figure J-1. Flow Chart of Data Reduction Program &ABRED.
con't

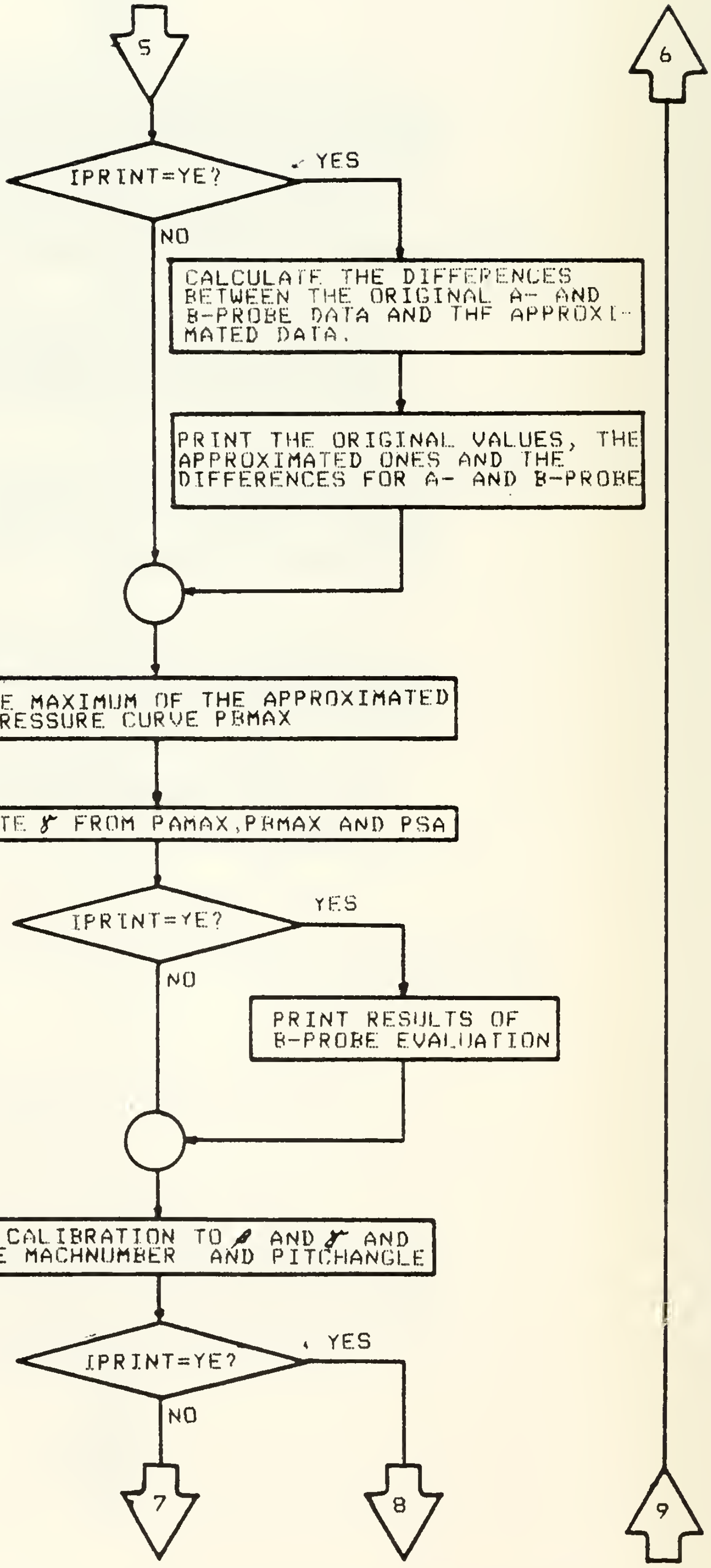


Figure J-1. Flow Chart of Data Reduction Program &ABRED.

con't

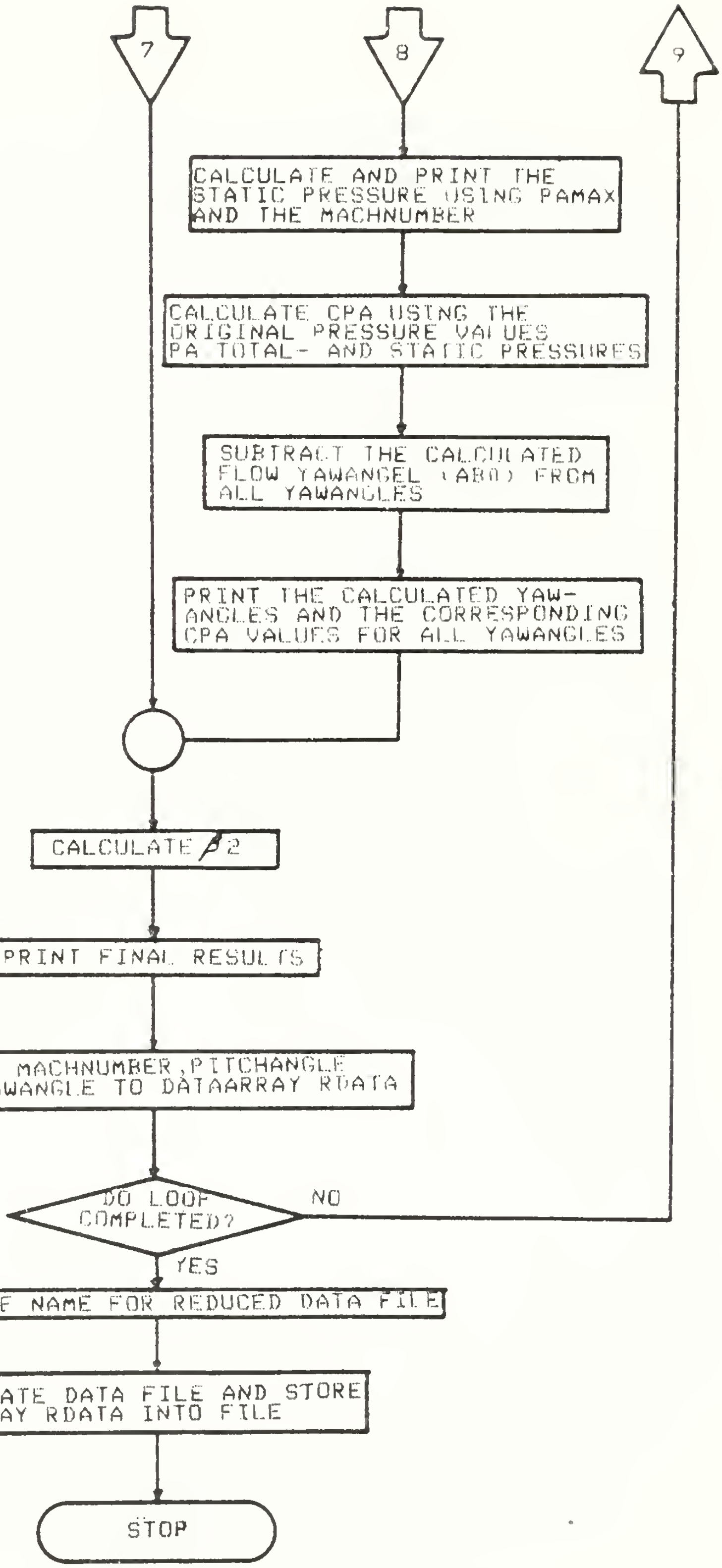


Figure J-1. Flow Chart of Data Reduction Program &ABRED.
con't

```
&ABRED T=00004 IS ON CR00027 USING 00142 BLKS R=0000

FTN4,L
      PROGRAM ABRED (3,99)
C     ..............................................................
C     .                                                            .
C     .    THIS IS PROGRAM ABRED(uction) FOR THE A-B PROBE SYSTEM.  .
C     .                                                            .
C     .  IN THIS VERY VERSION THE PROGRAM IS SET UP FOR THE NEW A-B-  .
C     .  PROBES (0.063" O.D., SCREEN WITH HOLES ON A CIRCLE ).       .
C     .                                                            .
C     .  IF ANY OTHER PROBES (KULITE AS WELL AS COMBINATION PROBE)   .
C     .  SHALL BE USED, THE CORRECT FILE NAMES FOR THE COEFFICIENT   .
C     .  FILES HAVE TO BE PUT IN :                                   .
C     .                                                            .
C     .  FILE #  CONTAINS APPROX. COEFFICIENTS:    DATA ARRAY NAME    .
C     .                                                            .
C     .    1     KULITE PROBES MACHNUMBER                COEKX        .
C     .    2     KULITE PROBES PITCHANGLE                COEKP        .
C     .    3     KULITE PROBES CP0B                      COECP        .
C     .    4     COMBINATION PROBE MACHNUMBER            COEOX        .
C     .    5     COMBINATION PROBE PITCHANGLE            COEOP        .
C     .                                                            .
C     ..............................................................
      COMMON / DTA2 / X1,Y
      REAL DATA(20,256),X1(256)   ,Y(256),COEF(7)
      REAL COEOX(7,7)   ,COEOP(7,7),COEKX(7,7),COEKP(7,7),COECPB(7,7)
      REAL              PAA(9)     ,PAB(9)     ,YAWA(9)    ,YAWB(9)
      REAL              PA(9)      ,PB(9)      ,PAC(9)     ,PREFP(9)
      REAL              RDATA(3,256)
      DIMENSION         CP0A(6)
      INTEGER           IDCB(144),IFILE(3),ISIZE(2)
      INTEGER           NOLF,NOCR(2),ICLR(3)
      DATA  CP0A(1)     / 1.0025921 /
      DATA  CP0A(2)     / 0.0356475 /
      DATA  CP0A(3)     / -.2724224 /
      DATA  CP0A(4)     / 0.9320285 /
      DATA  CP0A(5)     / -2.333180 /
      DATA  CP0A(6)     / 0.0000000 /
      DATA  IDCBS       /       144 /
      DATA  IITYPE      /         1 /
      DATA  ICLR        /015524B,015515B,006537B /
      DATA  NOLF        /    006537B /
  300 FORMAT (" OUTPUT INPUT DATA TO ANY OTHER DEVICE?  ENTER NO
     * OR LU# !"/"   "A2)
  305 FORMAT (I2)
  310 FORMAT ( " DO YOU WANT AN OUTPUT OF THE CALIBRATION COEFFICIENTS?"
     */" ENTER YES IF SO OR ANYTHING ELSE IF NOT!"/"    "A2)
  315 FORMAT ( " DO YOU WANT AN OUTPUT OF THE CONTROLL PARAMETERS?"/" KE
     *Y YES IF SO OR ANYTHING ELSE IF NOT!"/"    "A2)
  320 FORMAT (//" THE DATA READ FROM FILE "3A2" ARE"/)
  325 FORMAT (" I / J  "I0,5I12)
  330 FORMAT ("  "I3,7(1X,F11.6))
  335 FORMAT (" ENTER RAW DATA FILE!"//
     *" DON'T FORGET SECURITY CODE & CARTRIDGE REFERENCE NUMBER!"/
     *"          :   :   "A2)
  340 FORMAT ((3A2),1X,I2,1X,I2)
  345 FORMAT (" ENTER THE NUMBER OF THE START AND END POSITION :"/
     *"          "A2)
  350 FORMAT (I3,1X,I3)
  355 FORMAT (" ***************************************************"//
     *" RAW DATA FILE : "3A2"::"I3                                  //
     *          " ***************************************************"/)
  360 FORMAT(/" FLOW AVARAGED VALUES AS ESTABLISHED WITH THE COMBINATION
     * PROBE"//"  Ptotal(INCH H2O) Pstatic(INCH H2O)"6X"Xvel"6X"Mach"2X"
     *Phi(deg)"2X"Yaw(deg)"/2(5X,F13.6),2(2X,F8.5),2(3X,F7.2)/)
  365 FORMAT (" EQUATION FOR A-PROBE PRESSURE :"/" PA = "F12.6" + " F12.
     *6" * VOLTAGE(raw)*0.01 + PREF(INCH H2O)")
  370 FORMAT( " CP0A = "F10.5" CP0B = "F10.7)
  375 FORMAT (" EQUATION FOR B-PROBE PRESSURE :"/" PB = "F12.6" + " F12.
     *6" * VOLTAGE(raw)*0.01 + PREF(INCH H2O)")
  380 FORMAT     (/" #   PAA(#)   PAB(#) YAWA(#) YAWB(#)"/)
  385 FORMAT(I2,4(1X,F7.5))
  390 FORMAT(" A-PROBE APPROXIMATION RESULTS : YAW = "3(5X,F9.2)/16X" PR
     *ESSURE (INCH H2O) = "3(3X,F11.6)/29X" CPAMAX = "F8.4/)
  395 FORMAT(/" B-PROBE APPROXIMATION RESULTS : YAW0 = "F5.1" PRESSURE
     *(INCH H2O) ="F6.2//)
  400 FORMAT(" AVERAGE VALUE RESULTS FROM THE A-B SYSTEM:"//5X"BETA"4X"G
     *AMMA"5X"Xvel"4X"Pitch"6X"Yaw"7X"XU"6X"XAX"4X"BETA2"/3(F9.5),2(2X,F
     *7.2),2(F9.5),2X,F7.2)
```

Figure J-2. Listing of Data eduction Program &ABRED.
(Continued on next page.)

```
      405 FORMAT(//////////" POS#"6X"Beta"5X"Gamma"6X"Xvel"5X"Pitch"7X"Yaw"5
         *X"BETA2")
      410 FORMAT(" #    YAWA(I)      PA(I)     PAC(I)         DPA    YAWB(I)      P
         *B(I)     PBC(I)        DPB")
      415 FORMAT(I2,8(3X,F7.5))
      420 FORMAT (/"  PSTATIC (DERIVED FROM PAMAX AND XVEL) = "F8.3/)
      425 FORMAT ("   #  ACTUAL YAW ANGLE         CPA")
      430 FORMAT (I4,12X,F6.2,3X,F6.3)
      435 FORMAT(I5,3(F10.5),3(3X,F7.2))
      440 FORMAT(" ENTER THE NAME FOR THE FILE CONTAINING REDUCED DATA!"/
         *" DON'T FORGET SECURITY CODE & CARTRIDGE REFERENCE NUMBER!"/
         *"        :  :   "A2)
      445 FORMAT (//" REDUCED DATA STORED IN FILE : "3A2":"I2)
     1111 FORMAT (" STATEMENT # "I4" ERROR # : "F12.2"DETECTED ")
     1149 FORMAT ((3A2))
          LI = LOGLU(ISESSN)
      005 WRITE (LI, 300) NOLF
          READ  (LI,1149) IDUM
          WRITE (LI,1149) (ICLR,I11= 1,2)
          IF ( IDUM  .EQ.  2HNO ) GO TO 010
          CALL CODE
          READ  (IDUM,305) LO
          IF ( LO  .EQ.   1 ) GO TO 015
          IF ( LO  .EQ.   6 ) GO TO 015
          IF ( LO  .EQ.  18 ) GO TO 015
          GO TO 005
      010 LO = 0
      015 IF ( LO  .EQ.  LI ) LO = 0
          WRITE (LI, 310) NOLF
          READ  (LI,1149) IPRIN1
          WRITE (LI,1149) (ICLR,I11=1,3)
          WRITE (LI, 315) NOLF
          READ  (LI,1149) IPRINT
          WRITE (LI,1149) (ICLR,I11 = 1,3)
C         .................................................................
C         .                                                               .
C         .  READ COEFFICIENTFILE FOR THE KULITE MACHNUMBER APPROXIMATION .
C         .  FROM DISC INTO ARRAY COEKX(7,7).                             .
C         .                                                               .
C         .................................................................
          IFILE(1) = 2HMI
          IFILE(2) = 2HST
          IFILE(3) = 2HXV
          ISECU    = 00
          ICR      = 26
          CALL OPEN  (IDCB,IERR,IFILE,IOPTN,ISECU,ICR,IDCBS)
          JJ = 1
          IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
          CALL READF (IDCB,IERR,COEKX,98,LEN,1)
          JJ = 2
          IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
          CALL CLOSE (IDCB,IERR,0)
          JJ = 3
          IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
          IF (IPRIN1 .NE. 2HYE) GOTO 025
C         .................................................................
C         .                                                               .
C         .  OUTPUT INPUT DATA.                                           .
C         .                                                               .
C         .................................................................
          WRITE (LI, 320) IFILE
          IF ( LO  .NE.  0 ) WRITE (LO, 320) IFILE
          WRITE (LI, 325) (I1,I1=1,7)
          IF ( LO  .NE.  0 ) WRITE (LO, 325) (I1,I1=1,7)
          DO 020 I1=1,7,1
          IF ( LO  .NE.  0 ) WRITE (LO, 330) I1,(COEKX(I1,J1),J1=1,7,1)
      020 WRITE (LI, 330) I1,(COEKX(I1,J1),J1=1,7,1)
C         .................................................................
C         .                                                               .
C         .  READ COEFFICIENTFILE FOR THE KULITE PITCHANGLE APPROXIMATION .
C         .  FROM DISC INTO ARRAY COEKP(7,7).                             .
C         .                                                               .
C         .................................................................
      025 IFILE(1) = 2HMI
          IFILE(2) = 2HST
          IFILE(3) = 2HFI
          CALL OPEN  (IDCB,IERR,IFILE,IOPTN,ISECU,ICR,IDCBS)
          JJ = 4
          IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
          CALL READF (IDCB.IERR.COEKP.98.LEN,1)
```

Figure J-2. Listing on Data Reduction Program &ABRED.
(Continued on next page.)

```
      JJ = 5
      IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
      CALL CLOSE (IDCB,IERR,0)
      JJ = 6
      IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
      IF (IPRIN1 .NE. 2HYE) GOTO 035
C     ..................................................................
C     .                                                                .
C     .  OUTPUT INPUT DATA.                                            .
C     .                                                                .
C     ..................................................................
      WRITE (LI, 320) IFILE
      IF ( LO  .NE.  0 ) WRITE (LO, 320) IFILE
      WRITE (LI, 325) (I1,I1=1,7)
      IF ( LO  .NE.  0 ) WRITE (LO, 325) (I1,I1=1,7)
      DO 030 I1=1,7,1
      IF ( LO  .NE.  0 ) WRITE (LO, 330) I1,(COEKP(I1,J1),J1=1,7,1)
  030 WRITE (LI, 330) I1,(COEKP(I1,J1),J1=1,7,1)
C     ...................................................................
C     .                                                                 .
C     .  READ COEFFICIENTFILE FOR THE KULITE CP0B APPROXIMATION         .
C     .  FROM DISC INTO ARRAY COECP(7,7).                               .
C     .                                                                 .
C     ...................................................................
  035 IFILE(1) = 2HMI
      IFILE(2) = 2HST
      IFILE(3) = 2HCP
      CALL OPEN  (IDCB,IERR,IFILE,IOPTN,ISECU,ICR,IDCBS)
      JJ = 7
      IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
      CALL READF (IDCB,IERR,COECPB,98,LEN,1)
      JJ = 8
      IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
      CALL CLOSE (IDCB,IERR,0)
      JJ = 9
      IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
      IF (IPRIN1 .NE. 2HYE) GOTO 045
C     ..................................................................
C     .                                                                .
C     .  OUTPUT INPUT DATA.                                            .
C     .                                                                .
C     ..................................................................
      WRITE (LI, 320) IFILE
      IF ( LO  .NE.  0 ) WRITE (LO, 320) IFILE
      WRITE (LI, 325) (I1,I1=1,7)
      IF ( LO  .NE.  0 ) WRITE (LO, 325) (I1,I1=1,7)
      DO 040 I1=1,7,1
      IF ( LO  .NE.  0 ) WRITE (LO, 330) I1,(COECPB(I1,J1),J1=1,7,1)
  040 WRITE (LI, 330) I1,(COECPB(I1,J1),J1=1,7,1)
C     ..................................................................
C     .                                                                .
C     .  READ COEFFICIENTFILE FOR THE COMBINATIONPROBE MACHNUMBER      .
C     .  APPROXIMATION INTO ARRAY COEOX(7,7).                          .
C     .                                                                .
C     ..................................................................
  045 ICR      = 28
      IFILE(1) = 2HCO
      IFILE(2) = 2HEF
      IFILE(3) = 2H2X
      CALL OPEN  (IDCB,IERR,IFILE,IOPTN,ISECU,ICR,IDCBS)
      JJ = 10
      IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
      CALL READF (IDCB,IERR,COEOX,98,LEN,1)
      JJ = 11
      IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
      CALL CLOSE (IDCB,IERR,0)
      JJ = 12
      IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
      IF (IPRIN1 .NE. 2HYE) GOTO 055
C     ..................................................................
C     .                                                                .
C     .  OUTPUT INPUT DATA.                                            .
C     .                                                                .
C     ..................................................................
      WRITE (LI, 320) IFILE
      IF ( LO  .NE.  0 ) WRITE (LO, 320) IFILE
      WRITE (LI, 325) (I1,I1=1,7)
      IF ( LO  .NE.  0 ) WRITE (LO, 325) (I1,I1=1,7)
      DO 050 I1=1,7,1
      IF ( LO  .NE.  0 ) WRITE (LO, 330) I1,(COEOX(I1,J1),J1=1,7,1)
```

Figure J-2. Listing of Data Reduction Program &ABRED.
(Continued on next page.)

```
      050 WRITE (LI, 330) I1,(COEOX(I1,J1),J1=1,7,1)
C         ..................................................................
C         .                                                                .
C         .  READ COEFFICIENTFILE FOR THE COMBINATIONPROBE PITCHANGLE      .
C         .  APPROXIMATION INTO ARRAY COEOP(7,7).                          .
C         .                                                                .
C         ..................................................................
      055 IFILE(1) = 2HCO
          IFILE(2) = 2HEF
          IFILE(3) = 2H2P
          CALL OPEN  (IDCB,IERR,IFILE,IOPTN,ISECU,ICR,IDCBS)
          JJ = 13
          IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
          CALL READF (IDCB,IERR,COEOP,98,LEN,1)
          JJ = 14
          IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
          CALL CLOSE (IDCB,IERR,0)
          JJ = 15
          IF ( IERR  .LT.  0 ) WRITE (LI,1111) JJ,IERR
          IF (IPRIN1 .NE. 2HYE) GOTO 065
C         ..................................................................
C         .                                                                .
C         .  OUTPUT INPUT DATA.                                            .
C         .                                                                .
C         ..................................................................
          WRITE (LI, 320) IFILE
          IF ( LO  .NE.  0 ) WRITE (LO, 320) IFILE
          WRITE (LI, 325) (I1,I1=1,7)
          IF ( LO  .NE.  0 ) WRITE (LO, 325) (I1,I1=1,7)
          DO 060 I1=1,7,1
          IF ( LO  .NE.  0 ) WRITE (LO, 330) I1,(COEOP(I1,J1),J1=1,7,1)
      060 WRITE (LI, 330) I1,(COEOP(I1,J1),J1=1,7,1)


      065 WRITE (LI, 335) NOLF
          READ  (LI, 340) IFILE,ISECU,ICR
          WRITE (LI,1149) (ICLR,I1 =1,3)
          IL        = 10240
          ISIZE(1) =    80
          ISIZE(2) =   128
          CALL OPEN  (IDCB,IERR,IFILE,IOPTN,ISECU,ICR,IDCBS)
          JJ = 13
          IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
          CALL READF (IDCB,IERR,DATA,IL,LEN,1)
          JJ = 14
          IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
          CALL CLOSE (IDCB,IERR,0)
          JJ = 15
          IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
          WRITE (LI,345) NOLF
          READ  (LI,350) ISTART,IEND
          WRITE (LI,355) IFILE,ICR
          IF ( LO .NE . 0 ) WRITE (LO,355) IFILE,ICR
C         ..................................................................
C         .                                                                .
C         .  COMBINATION PROBE DATA REDUCTION.                             .
C         .                                                                .
C         ..................................................................
          P1         = 0.0
          P23        = 0.0
          P4         = 0.0
          PREF       = 0.0
          RPM        = 0.0
          RADIS      = 0.0
          YAW        = 0.0
          TT2        = 0.0
          DO 070 I = 1,9,1
          J          = (I-1) * 20
          PBARO      = DATA(20,J+7)*1.3585
          P1         = P1  + (DATA(20,J+ 3) - DATA(20,J+ 1) + PBARO)*100*1000
          P23        = P23 + (DATA(20,J+ 4) - DATA(20,J+ 1) + PBARO)*100*1000
          P4         = P4  + (DATA(20,J+ 5) - DATA(20,J+ 1) + PBARO)*100*1000
          PREF       = PREF+  DATA(20,J+14) * 100 * 1000
          RPM        = RPM +  DATA(20,J+6)  * 10
          RADIS      = RADIS+(DATA(20,J+8)+DATA(20,J+10)+DATA(20,J+12))/3*1000
          YAW        = YAW +  DATA(20,J+9) * 10000
      070 TT2        = TT2   + (DATA(20,J+15) + DATA(20,J+16)) * 1000
          P1         = P1  / 9
          P23        = P23 / 9
          P4         = P4  / 9
```

Figure J-2. Listing of Data Reduction Program &ABRED.
(Continued on next page.)

```
      PREF     = PREF/ 9
      RPM      = RPM / 9
      RADIS    = RADIS  / 9
      RADIS    = 5.51 - RADIS
      YAW      = YAW / 9
      TT2      = TT2 / 9
      TT2      = 31.9557 + 30.6827 * TT2 - 0.3679 * TT2 * TT2
      TT2      = ((TT2 - 32) * 5 / 9 ) + 273.15
      VT2      = SQRT ( 2008 * TT2 )
      U        = (RPM / 60) * RADIS * 2 * 3.14159 * 0.0254
      XU       = U   / VT2
      BETA     = ( P1 - P23 ) / P1
      GAMMA    = ( P1 - P4  ) / ( P1 - P23 )
      DELTA    = GAMMA * BETA

      XVEL     = 0.0
      PHI      = 0.0
      DO 075 I1 = 1,7,1
      DO 075 I2 = 1,7,1
      XVEL     = XVEL + (COEOX(I1,I2)*DELTA**(I2-1))*GAMMA**(I1-1)
  075 PHI      = PHI  + (COEOP(I1,I2)*DELTA**(I2-1))*GAMMA**(I1-1)
      XM       = SQRT ((2/(1.402-1))*((XVEL*XVEL)/(1-(XVEL*XVEL))))
      PTOTAL   = P1
      PSTAT    = PTOTAL * (1-XVEL*XVEL)**(1.402/.402)
      WRITE (LI,360) PTOTAL,PSTAT,XVEL,XM,PHI,YAW
      IF ( LO .NE. 0 ) WRITE (LO,360) PTOTAL,PSTAT,XVEL,XM,PHI,YAW
C     ...............................................................
C     .                                                             .
C     .     PERFORM ONLINE CALIBRATION. A-PROBE FIRST.              .
C     .                                                             .
C     ...............................................................

C     ...............................................................
C     .                                                             .
C     .     FIND MAXIMUM OUTPUT OF A-PROBE.                         .
C     .                                                             .
C     ...............................................................
      DO 080 I = 1,9,1
      J        = (I-1) * 20
      X1(I)    = DATA(20,J+11) * 10000 * 3.14159 / 180
  080 Y (I)    = DATA(20,J+17)
      CALL MAT2 (9,5,COEF,-4)
C     ...............................................................
C     .                                                             .
C     .   INITIAL ESTIMATE FOR THE APPROXIMATION IS :YAW = 22 (deg) .
C     .                                                             .
C     ...............................................................
      X0       = 0.4
  085 DEAMAX   = FND (4,COEF,X0)
      IF(ABS(DEAMAX) .LT. 0.0001 ) GOTO 090
      X0 = X0 - DEAMAX / (2*COEF(3)+6*COEF(4)*X0+12*COEF(5)*X0*X0)
      GOTO 085
  090 EAMAX    = FNP(4,COEF,X0)
      SLOPEA   = (DATA(1,160) + DATA(1,180))/(-2.0)*100*1000
      PHI      = PHI * 3.14159 / 180.
C     ...............................................................
C     .                                                             .
C     .    CALCULATE CP0A(EQ3) FROM COMBINATION PROBE RESULTS (PITCH) .
C     .                                                             .
C     ...............................................................
      EQ3      = FNP (4,CP0A,PHI)
      PAMAX    = EQ3 * (PTOTAL-PSTAT) + PSTAT
      SECTA    = PAMAX - PREF - SLOPEA * EAMAX
      P0A      = SECTA + SLOPEA * EAMAX + PREF
      IF ( IPRINT .NE. 2HYE ) GOTO 095
      WRITE (LI,365) SECTA,SLOPEA
      IF (LO .NE. 0 ) WRITE (LO,365) SECTA,SLOPEA
  095 CONTINUE
C     ...............................................................
C     .                                                             .
C     .   B-PROBE CALIBRATION.                                      .
C     .   FIND MAXIMUM OUTPUT FIRST.                                .
C     .                                                             .
C     ...............................................................
      DO 100 I = 1,8,1
      J        = ( I-1) * 20
      X1(I)    = DATA(20,J+13) * 10000 * 3.14159 / 180
  100 Y (I)    = DATA(20,J+18)
      CALL MAT2 (8,5,COEF,-4)
C     ...............................................................
```

Figure J-2. Listing of Data Reduction Program &ABRED.
(Continued on next page.)

```
C     :                                                                 :
C     :     INITIAL ESTIMATE FOR THE APPROXIMATION IS : YAW = 0 (deg)   :
C     :                                                                 :
C     ...................................................................
      X0         = 0.0
  105 DEBMA      = FND (4,COEF,X0)
      IF (ABS(DEBMA)  .LT. 0.00001 ) GOTO 110
      X0         = X0 - DEBMA  / (2*COEF(3)+6*COEF(4)*X0+12*COEF(5)*X0*X0)
      GOTO 105
  110 EBMAX      = FNP (4,COEF,X0)
      PSTATA     = PSTAT - PREF
      EQS        = 0.0
C     ...................................................................
C     :                                                                 :
C     :     CALCULATE CP0B FROM COMBINATION PROBE RESULTS.              :
C     :                                                                 :
C     ...................................................................
      DO 115 I1 = 1,5,1
      DO 115 J1 = 1,5,1
  115 EQS         = EQS + (COECPB(I1,J1)*XVEL**(J1-1))*PHI**(I1-1)
      WRITE (LI,370) EQ3,EQS
      IF (LO .NE. 0) WRITE (LO,370) EQ3,EQS
      P0B        = EQS * (PTOTAL-PSTAT) + PSTAT
      PKB        = P0B + PREF
      SLOPEB     = (DATA(1,170) + DATA(1,190) ) / (-2.0) * 100*1000
      SECTB      = PKB - PREF - SLOPEB * EBMAX
      IF ( IPRINT .NE. 2HYE ) GOTO 120
      WRITE (LI,375) SECTB,SLOPEB
      IF (LO .NE. 0 ) WRITE (LO,375) SECTB,SLOPEB
  120 CONTINUE

C     ...................................................................
C     :                                                                 :
C     :   START DATA REDUCTION.                                         :
C     :   FIRST CALCULATE THE AVERAGE FLOW PARAMETERS USING THE         :
C     :   OVERALL VALUES FROM THE A AND B PROBE AND THE JUST            :
C     :   ESTABLISHED CALIBRTION.                                       :
C     :                                                                 :
C     ...................................................................
      DO 125 I = 1,9,1
      J          = (I-1) * 20
      PAA(I)     = DATA(20,J+17)
      PAB(I)     = DATA(20,J+18)
      PAA(I)     = SECTA + SLOPEA * PAA(I) + DATA(20,J+14)*100*1000
      PAB(I)     = SECTB + SLOPEB * PAB(I) + DATA(20,J+14)*100*1000
      YAWA(I)    = DATA(20,J+11) * 10000
  125 YAWB(I)    = DATA(20,J+13) * 10000
      IF ( IPRINT .NE. 2HYE ) GOTO 135
      WRITE (LI,380)
      IF (LO .NE. 0 ) WRITE (LO,380)
      DO 130 I = 1,9,1
      WRITE(LI,385) I,PAA(I),PAB(I),YAWA(I),YAWB(I)
  130 IF(LO .NE. 0) WRITE(LO,385) I,PAA(I),PAB(I),YAWA(I),YAWB(I)
  135 CONTINUE
C     ...................................................................
C     :                                                                 :
C     :      APPROXIMATE A-PROBE PRESSURES.                             :
C     :                                                                 :
C     ...................................................................
      DO 140 I = 1,9,1
      X1(I)       = YAWA(I)
  140 Y (I)       = PAA (I)
      CALL MAT2 (9,5,COEF,-4)
C     ...................................................................
C     :                                                                 :
C     :  FIND MAX. OUTPUT OF A PROBE.                                   :
C     :                                                                 :
C     ...................................................................
      DX          =  126.0
      X0          =  -40.0
  145 DP          = (FNP(4,COEF,X0) - FNP(4,COEF,(X0+DX)))
      IF (ABS(DP) .LT. 0.0001 ) GOTO 150
      DPX  = -2.0*COEF(3)*DX-6.0*COEF(4)*X0*DX-3.0*COEF(4)*DX*DX-
     *        12.0*COEF(5)*X0*X0*DX-12*COEF(5)*X0*DX*DX-4.0*COEF(5)*DX**3
      X0          = X0 - DP / DPX
      GOTO 145
  150 ASL         = X0
      ASR         = X0 + DX
      AA0         = X0 + DX / 2.0
      PAMAX       = FNP(4,COEF,AA0)
```

Figure J-2. Listing of Data Reduction Program &ABRED.
(Continued on next page.)

```
      PSAL      = FNP(4,COEF,ASL)
      PSAR      = FNP(4,COEF,ASR)
      PSA       = (PSAL + PSAR ) / 2.0

      BETA      = (PAMAX - PSA ) / PAMAX
      CPAMAX    = (PAMAX - PSA ) / ( PTOTAL - PSA )
      IF ( IPRINT .NE. 2HYE ) GOTO 155
      WRITE (LI,390) ASL,AA0,ASR,PSAL,PAMAX,PSAR,CPAMAX
      IF (LO .NE. 0 ) WRITE (LO,390) ASL,AA0,ASR,PSAL,PAMAX,PSAR,CPAMAX
  155 CONTINUE
C     ..............................................................
C     .                                                            .
C     .   APPROXIMATE B PROBE PRESSURES.                           .
C     .                                                            .
C     ..............................................................
      DO 160 I = 1,9,1
      X1(I)     = YAWB(I)
  160 Y (I)     = PAB (I)
      CALL MAT2 (9,5,COEF,-4)
C     ...............................................................
C     .                                                             .
C     .     FIND MAXIMUM OUTPUT OF B-PROBE.                         .
C     .                                                             .
C     ...............................................................
      X0        =  0.00
  165 DPX       = FND(4,COEF,X0)
      IF ( ABS(DPX) .LT. 0.00001 ) GOTO 170
      X0    = X0 - DPX /(2*COEF(3) + 6*COEF(4)*X0 + 12*COEF(5)*X0*X0)
      GOTO 165
  170 AB0       = X0
      PBMAX     = FNP(4,COEF,AB0)
      IF ( IPRINT .NE. 2HYE ) GOTO 175
      WRITE (LI,395) AB0,PBMAX
      IF ( LO .NE. 0 ) WRITE (LO,395) AB0,PBMAX
  175 CONTINUE
      CPBMAX    = ( PBMAX - PSA ) / (PTOTAL - PSA )
      GAMMA     = (CPAMAX - CPBMAX ) / CPAMAX
      XVEL      = 0.0
      PHI       = 0.0
      DO 180 I1 = 1,7,1
      DO 180 I2 = 1,7,1
      XVEL      = XVEL + (COEKX(I1,I2) *GAMMA**(I2-1))* BETA**(I1-1)
  180 PHI       = PHI  + (COEKP(I1,I2) *GAMMA**(I2-1))* BETA**(I1-1)
      PHI       = PHI  * 180 / 3.14159
      XAX    = XVEL * COS(PHI*3.14159/180) * COS(AB0*3.14159/180)
      BETA2  = ATAN((XU-XVEL*COS(PHI*3.14159/180)*SIN(AB0*3.14159/180))
     *          / XAX) * 180 / 3.14159
      WRITE (LI,400) BETA,GAMMA,XVEL,PHI,AB0,XU,XAX,BETA2
      IF(LO .NE. 0) WRITE (LO,400) BETA,GAMMA,XVEL,PHI,AB0,XU,XAX,BETA2
C     ............................................................
C     .                                                          .
C     .     START OF DATA REDUCTION FOR INDIVIDUAL POSITIONS.    .
C     .                                                          .
C     ............................................................


C     ............................................................
C     .                                                          .
C     .    Calculation of values which are valid for all positions.  .
C     .                                                          .
C     ............................................................
      WRITE (LI,405)
      IF ( LO .NE. 0 ) WRITE (LO,405)
      DO 185 I = 1,9,1
      J         = (I-1) * 20
      YAWA(I)   = DATA(20,J+11) * 10000
      YAWB(I)   = DATA(20,J+13) * 10000
  185 PREFP(I) = DATA(20,J+14) * 100*1000
C     ................................................................
C     .                                                              .
C     .   START OF DO LOOP !                                         .
C     .                                                              .
C     ................................................................
      DO 270 I = ISTART,IEND,1
      DO 190 J = 1,  9,1
      J1        = J * 2
      J2        = J * 2 + 1
      PA(J)     = DATA(J1,I) * 0.01
      PB(J)     = DATA(J2,I) * 0.01
      PA(J)     = SECTA + SLOPEA * PA(J) + PREFP(J)
```

Figure J-2. Listing of Data Reduction Program &ABRED.
(Continued on next page.)

```
  190 PB(J)     = SECTB + SLOPEB * PB(J) + PREFP(J)
C     ..............................................................
C     .                                                            .
C     .  Approximate A-probe output.                               .
C     .                                                            .
C     ..............................................................
      DO 195 I1 = 1,9,1
      X1(I1)      = YAWA(I1)
  195 Y (I1)      = PA   (I1)
      CALL MAT2 (9,5,COEF,-4)
      DO 200 I1 = 1,9,1
  200 PAC(I1)     = FNP (4,COEF,YAWA(I1))
C     ..............................................................
C     .                                                            .
C     .  FIND MAX. OUTPUT OF A PROBE.                              .
C     .                                                            .
C     ..............................................................
      DX    =  126.0
      X0    =  -40.0
  205 DP    = (FNP(4,COEF,X0) - FNP(4,COEF,(X0+DX)))
      IF (ABS(DP) .LT. 0.001 ) GOTO 210
      DPX   = -2.0*COEF(3)*DX-6.0*COEF(4)*X0*DX-3.0*COEF(4)*DX*DX-
     *        12.0*COEF(5)*X0*DX*DX-12*COEF(5)*X0*X0*DX-4.0*COEF(5)*DX**3
      X0    = X0 - DP / DPX
      GOTO 205
  210 ASL   = X0
      ASR   = X0 + DX
      AA0   = X0 + DX / 2.0
      PAMAX= FNP(4,COEF,AA0)
      PSAL = FNP(4,COEF,ASL)
      PSAR = FNP(4,COEF,ASR)
      PSA  = (PSAL + PSAR ) / 2.0

      BETA = (PAMAX - PSA ) / PAMAX
      CPAMAX= (PAMAX - PSA ) / ( PTOTAL - PSA )
      IF (IPRINT .NE. 2HYE ) GOTO 215
      WRITE (LI,390) ASL,AA0,ASR,PSAL,PAMAX,PSAR,CPAMAX
      IF (LO .NE. 0 ) WRITE (LO,390) ASL,AA0,ASR,PSAL,PAMAX,PSAR,CPAMAX
  215 CONTINUE
C     ..............................................................
C     .                                                            .
C     .   APPROXIMATE B PROBE PRESSURES.                           .
C     .                                                            .
C     ..............................................................
      DO 220 I1 = 1,9,1
      X1(I1)      = YAWB(I1)
  220 Y (I1)      = PB   (I1)
      CALL MAT2 (9,5,COEF,-4)
      IF (IPRINT .NE. 2HYE ) GOTO 225
      WRITE (LI,410)
      IF (LO .NE. 0 ) WRITE (LO,410)
  225 CONTINUE
C     ..............................................................
C     .                                                            .
C     .     CALCULATE AND PRINT QUALITY OF APPROXIMATIONS.         .
C     .                                                            .
C     ..............................................................
      DO 230 I1 = 1,9,1
      PBC         = FNP (4,COEF,YAWB(I1))
      DPA         = PA(I1) - PAC(I1)
      DPB         = PB(I1) - PBC
      IF (IPRINT .NE. 2HYE ) GOTO 230
      WRITE (LI,415) I1,YAWA(I1),PA(I1),PAC(I1),DPA,YAWB(I1),PB(I1),PBC,
     *DPB
      IF (LO .NE. 0) WRITE (LO,415) I1,YAWA(I1),PA(I1),PAC(I1),DPA,
     *YAWB(I1),PB(I1),PBC,DPB
  230 CONTINUE
C     ..............................................................
C     .                                                            .
C     .     FIND MAXIMUM OUTPUT OF B-PROBE.                        .
C     .                                                            .
C     ..............................................................
      X0          = 10.00
  235 DPX         = FND(4,COEF,X0)
      IF ( ABS(DPX) .LT. 0.001 ) GOTO 240
      X0    = X0 - DPX /(2*COEF(3) + 6*COEF(4)*X0 + 12*COEF(5)*X0*X0)
      GOTO 235
  240 AB0         = X0
      PBMAX       = FNP(4,COEF,AB0)
      IF (IPRINT .NE. 2HYE ) GOTO 245
```

Figure J-2. Listing of Data Reduction Program &ABRED.
(Continued on next page.)

```
      WRITE (LI,395) AB0,PBMAX
      IF ( LO .NE. 0 ) WRITE (LO,395) AB0,PBMAX
  245 CONTINUE
      CPBMAX     = ( PBMAX - PSA ) / (PTOTAL - PSA )
      GAMMA      = (CPAMAX - CPBMAX ) / CPAMAX
      XVEL       = 0.0
      PHI        = 0.0
      DO 250 I1 = 1,7,1
      DO 250 I2 = 1,7,1
      XVEL       = XVEL + (COEKX(I1,I2) *GAMMA**(I2-1))* BETA**(I1-1)
  250 PHI        = PHI  + (COEKP(I1,I2) *GAMMA**(I2-1))* BETA**(I1-1)
      IF (IPRINT .NE. 2HYE ) GOTO 265
      PSTAT      = PAMAX * ( 1 - XVEL*XVEL ) ** 3.5
      WRITE (LI,420) PSTAT
      IF (LO .NE. 0 ) WRITE (LO,420) PSTAT
      WRITE (LI,425)
      IF (LO .NE. 0 ) WRITE (LO,425)
      DO 260 I1 = 1,9,1
      CPA        = (PA(I1) - PSTAT) / (PAMAX - PSTAT)
      YAW        = YAWA(I1)- AB0
      WRITE (LI,430) I1,YAW,CPA
      IF (LO .NE. 0 ) WRITE (LO,430) I1,YAW,CPA
  260 CONTINUE
  265 CONTINUE
      PHI       = PHI  *  180 / 3.14159
      BETA2     = ATAN ((XU - XVEL * SIN(AB0 * 3.14159 / 180) *
     *                           COS(PHI * 3.14159 / 180)) /
     *            (XVEL*COS(AB0*3.14159/180)*COS(PHI*3.14159/180)))*
     *            180 / 3.14159
C     ..................................................................
C     .                                                                .
C     .     PRINT FLOW VECTOR QUANTITIES FOR INDIVIDUAL POSITIONS.     .
C     .                                                                .
C     ..................................................................
      WRITE (LI,435) I,BETA,GAMMA,XVEL,PHI,AB0,BETA2
      IF (LO .NE. 0) WRITE (LO,435) I,BETA,GAMMA,XVEL,PHI,AB0,BETA2
      RDATA(1,I) = XVEL
      RDATA(2,I) = PHI
      RDATA(3,I) = AB0
  270 CONTINUE

C     ..................................................................
C     .                                                                .
C     .     STORE REDUCED DATA IN A DATA FILE.                         .
C     .                                                                .
C     ..................................................................
      IL        =  1536
      ISIZE(2) =     12
      WRITE (LI,440) NOLF
      READ  (LI,340) IFILE,ISECU,ICR
      CALL  CREAT (IDCB,IERR,IFILE,ISIZE,ITYPE,ISECU,ICR,IDCBS)
      JJ = 16
      IF (IERR .LT. 0 ) WRITE(1,1111) JJ,IERR
      CALL   OPEN (IDCB,IERR,IFILE,IOPTN,ISECU,ICR,IDCBS)
      JJ = 17
      IF (IERR .LT. 0 ) WRITE(1,1111) JJ,IERR
      CALL   WRITF (IDCB,IERR,RDATA,IL)
      JJ = 18
      IF (IERR .LT. 0 ) WRITE(1,1111) JJ,IERR
      CALL   CLOSE (IDCB,IERR,0)
      JJ = 19
      IF (IERR .LT. 0 ) WRITE(1,1111) JJ,IERR
      WRITE (LI,445) IFILE,ICR
      IF (LO .NE. 0 ) WRITE (LO,445) IFILE,ICR
      STOP 7777
      END
      REAL FUNCTION FNP(NORDER,COEFF,ZX)
      REAL COEFF(7)
      A1 = COEFF(NORDER+1)
      IF ( NORDER .EQ. 0 ) GOTO 02
      DO 01 I1 = 1,NORDER,1
      I = NORDER + 1 - I1
   01 A1= COEFF(I)+ZX*A1
   02 FNP = A1
      RETURN
      END
      REAL FUNCTION FND(NORDER,COEFF,ZX)
      REAL COEFF (7)
      REAL COEFFD(6)
      DO 01 I=1,NORDER,1
   01  COEFFD(I) = COEFF(I+1)*I
       A1    = COEFFD(NORDER)
       NORDR= NORDER - 1
       IF( NORDR  .EQ. 0 ) GOTO 03
       DO 02 I1 = 1,NORDR,1
       I = (NORDR + 1) -I1
   02  A1 = COEFFD(I)+ZX*A1
   03  FND =A1
       RETURN
       END
```

Figure J-2. Listing of Data Reduction Program &ABRED.

APPENDIX K

PLOTT PROGRAMS FOR REDUCED DATA

The plot programs &PLOTX, &PLOTY and &PLOTP can be used to produce plots of the results obtained from the A and B probe. They are all almost identical except for which quantities of the flow vector they plot and the corresponding limits of the plots. Only one program description and one flow chart are given and the differences between the three programs are pointed out where they appear.

First, the program asks the user to key in the name of the data file containing the reduced data along with its cartridge reference number. This file is then read into an array DATA(3,256). The user has to decide whether he would like a plot on the X-Y plotter or just on the screen. Plots on the screen are much faster than those from the X-Y plotter and it is often only necessary to get a fast idea of the general value of the reduced data. However, X-Y plots are rather useful for documentation purposes. Once this decision is made either way, the use of the plot has to be specified. This must be done at any time the program is used. The physical dimensions of the plot have to be matched to the particular needs of the user.

Plot sizes have to be given in inches times ten. One inch is set equal to 25 millimeters (instead of 25.4 mm) by the HP plotter software. The values of XMIN and YMIN (lower left corner of plot) should not be smaller than 5.0 (0.5 inches or 12.5 mm), in order to leave sufficient space for the line titles. It is advisable to scale the lengths of the axes in a way that even measures in inches correspond to even numbers of the quantities plotted. For example, 10 degrees in yaw angle equivalent to 1 inch. Following are the limits of the quantities to be plotted:

For all programs:	$0 \leq$ circumferential position ≤ 256
Program PCOTX:	$0.12 \leq$ X (Mach number equivalent) ≤ 0.20
Program PCOTP:	$-4° \leq$ pitch angle $\leq 16°$
Program PCOTY:	$10° \leq$ yaw angle $\leq 50°$

Before the programs are used, the operator should check to see if his data falls within these limits. If it exceeds any limits, adjustments have to be made in the corresponding program line #67.

In order to compare different sets of data it is often helpful to plot the data from two or more files on one plot. To avoid having the same grid plotted any time one set of data is plotted, the user has to specify whether he wants to have a full grid (frame) plotted or not. He is also given a choice of 7 different line styles in order to distinguish similar but different data. For details of the line styles and plot software details see Ref. 11.

Once all this input is given the desired program will produce a plot as specified. In case of the X-Y plotter the number one pen is selected automatically by the program.

Thus the user should make sure that a good pen of the right color is inserted in that slot. When the complete graph is drawn, the program will stop.

Figure K-1 gives a flow chart of the program while Fig. K-2 is a program listing.

<u>Esternals</u>: CLOSE, DRAW, FXD, MOVE, OPEN, PLOTR, READF, SETAR, VIEWP, WINDW

<u>Variable</u>	<u>Type</u>	<u>Description</u>
DATA(3,256)	Real	Reduced data array
IBUM	Integer	Dummy variable
ICR	Integer	Cartridge reference number
ID	Integer	
IDCB(144)	Integer	Data control block
IDCBS	Integer	Control block length (of IDCB)
IDUM	Integer	Dummy variable
IFILE(3)	Integer	Array containing file name
IGCB(192)	Integer	Graphic data control block
IL	Integer	Total number of words to be stored in raw data file (two words for one data value)
ILINE	Integer	Line style determinator
ISECU	Integer	Security code
ISIZE(2)	Integer	Array to specify file dimensions (1st word for number of records, 2nd for record length)
ITYPE	Integer	Type of data file
LU	Integer	Output device number (screen/plotter)
X(256)	Real	Data array for X values

Variable	Type	Description
XMAX	Real	Maximum value of physical plot size (right side)
XMIN	Real	Minimum value of physical plot size (left side)
Y(256)	Real	Data array for Y values
YMAX	Real	Maximum value of physical plot size (upper limit)
YMIN	Real	Minimum value of physical plot size (lower limit)

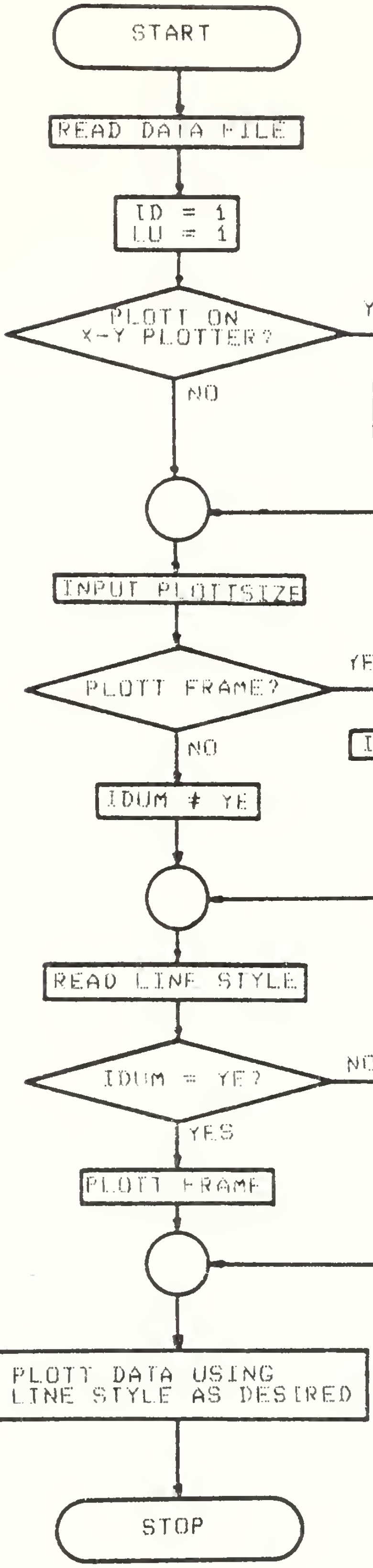


Figure K-1. Flow Chart of Plot Programs &PLOTX, &PLOTY or &PLOTP.

```
&PLOTX T=00004 IS ON CR00026 USING 00014 BLKS R=0000

FTN4,L
      PROGRAM PLOTX (3,99)
C     ..................................................................
C     .                                                                .
C     .    THIS IS PROGRAM PLOTX(vel)                                  .
C     .                                                                .
C     .    IT PLOTTS X (MACHNUMBER) DISTRIBUTIONS AS ESTABLISHED WITH  .
C     .    PROGRAM ABRED.                                              .
C     .    X IS EQUIVALENT TO MACHNUMBER AND GIVEN AS A FUNCTION OF    .
C     .    CIRCUMFERRENTIAL POSITION.                                  .
C     .                                                                .
C     .    ACTUAL PLOTTSIZE IS USER INPUT.                             .
C     .                                                                .
C     ..................................................................
      DIMENSION IGCB(172)
      REAL       DATA(4,256),X(256),Y(256)
      INTEGER    IDCB(144),IFILE(3),ISIZE(2)
      DATA       IDCBS     /  144/
      DATA       ISECU     /   00/
      DATA       ITYPE     /    1/
      DATA       IL        / 2048/
      DATA       ISIZE(1)  /   16/
      DATA       ISIZE(2)  /  128/
  100 FORMAT ("Enter the name of the data file!")
  101 FORMAT ("Enter the CR number!")
  102 FORMAT(" If you want the plott on the plotter, key PL, anythingels
     #e for the terminal !")
  103 FORMAT ("Enter Xplotmin !")
  104 FORMAT ("Enter Xplotmax !")
  105 FORMAT ("Enter Yplotmin !")
  106 FORMAT ("Enter Yplotmax !")
  107 FORMAT(" Do you need a complete new frame?"/" Answer YES or NO!")
  108 FORMAT (" Enter line style  (0 - 6) !")
  149 FORMAT ((3A2))
 1111 FORMAT (" STATEMENT # :"I3" ERROR # : "I4" DETECTED")
      LI = LOGLU(ISESSN)
      WRITE (LI,100)
      READ  (LI,149) IFILE
      WRITE (LI,101)
      READ  (LI,  *) ICR
      CALL OPEN  (IDCB,IERR,IFILE,IOPTN,ISECU,ICR,IDCBS)
      JJ = 1
      IF (IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
      CALL READF (IDCB,IERR,DATA,IL,LEN,1)
      JJ = 2
      IF (IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
      JJ = 3
      CALL CLOSE (IDCB,IERR,0)
      IF (IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
      LU = 1
      ID = 1
      WRITE (LI,102)
      READ  (LI,149) IBUM
      IF (IBUM .EQ. 2HPL ) ID = 2
      IF (ID   .EQ. 2    ) LU = 13
      WRITE (LI,103)
      READ  (LI,  *) XMIN
      WRITE (LI,104)
      READ  (LI,  *) XMAX
      WRITE (LI,105)
      READ  (LI,  *) YMIN
      WRITE (LI,106)
      READ  (LI,  *) YMAX
      CALL PLOTR (IGCB,ID,1,LU)
      CALL SETAR (IGCB,1.5)
      CALL VIEWP (IGCB,XMIN,XMAX,YMIN,YMAX)
      CALL WINDW (IGCB,0.0,256.0,0.18,0.24)
      WRITE (LI,107)
      READ  (LI,149) IDUM
      WRITE (LI,108)
      READ  (LI,  *) ILINE
      CALL LINE (IGCB,ILINE)
      IF ( IDUM .NE. 2HYE ) GOTO  05
      CALL FXD   (IGCB,2)
      CALL PEN   (IGCB,1)
      CALL LGRID (IGCB,-16.,.01,0.0,0.12,4.0,2.0,1.0)
   05 CONTINUE
      CALL MOVE  (IGCB,0.0,DATA(1,1))
      DO 10 I = 1,256,1
      XJ      = I * 1.0
   10 CALL DRAW  (IGCB,XJ,DATA(1,I))
      STOP 7777
      END
```

Figure K-2. Listing of Reduced Data Plott Program &PLOTX.

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